STUDY ON SUBSIDENCE DUE TO UNDERGROUND COAL MINING

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by

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INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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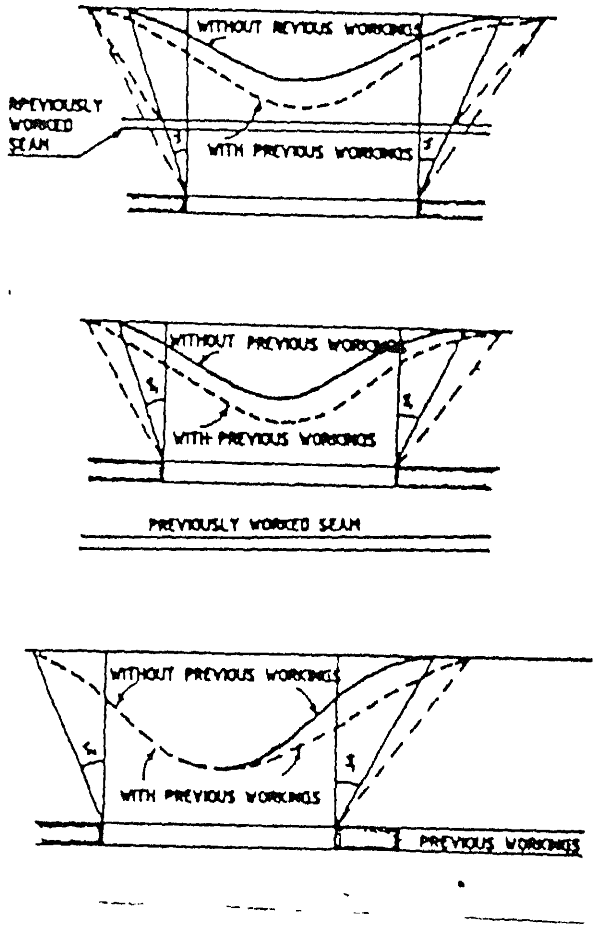

Fig. 2.7 Effect of overlying or previous work

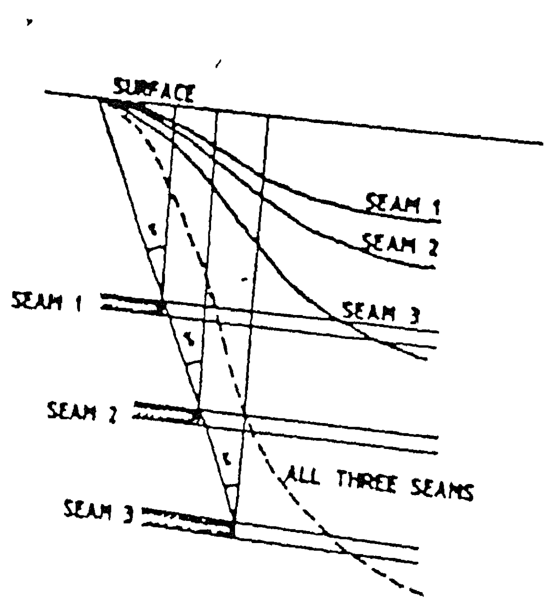

Fig. 2.8 Subsidence due to multiple seam extraction

CERTIFICATE

It is certified that the work contained in this thesis entitled STUDY ON SUBSIDENCE DUE TO UNDERGROUND COAL MINING, by Ram Naresh Yadav has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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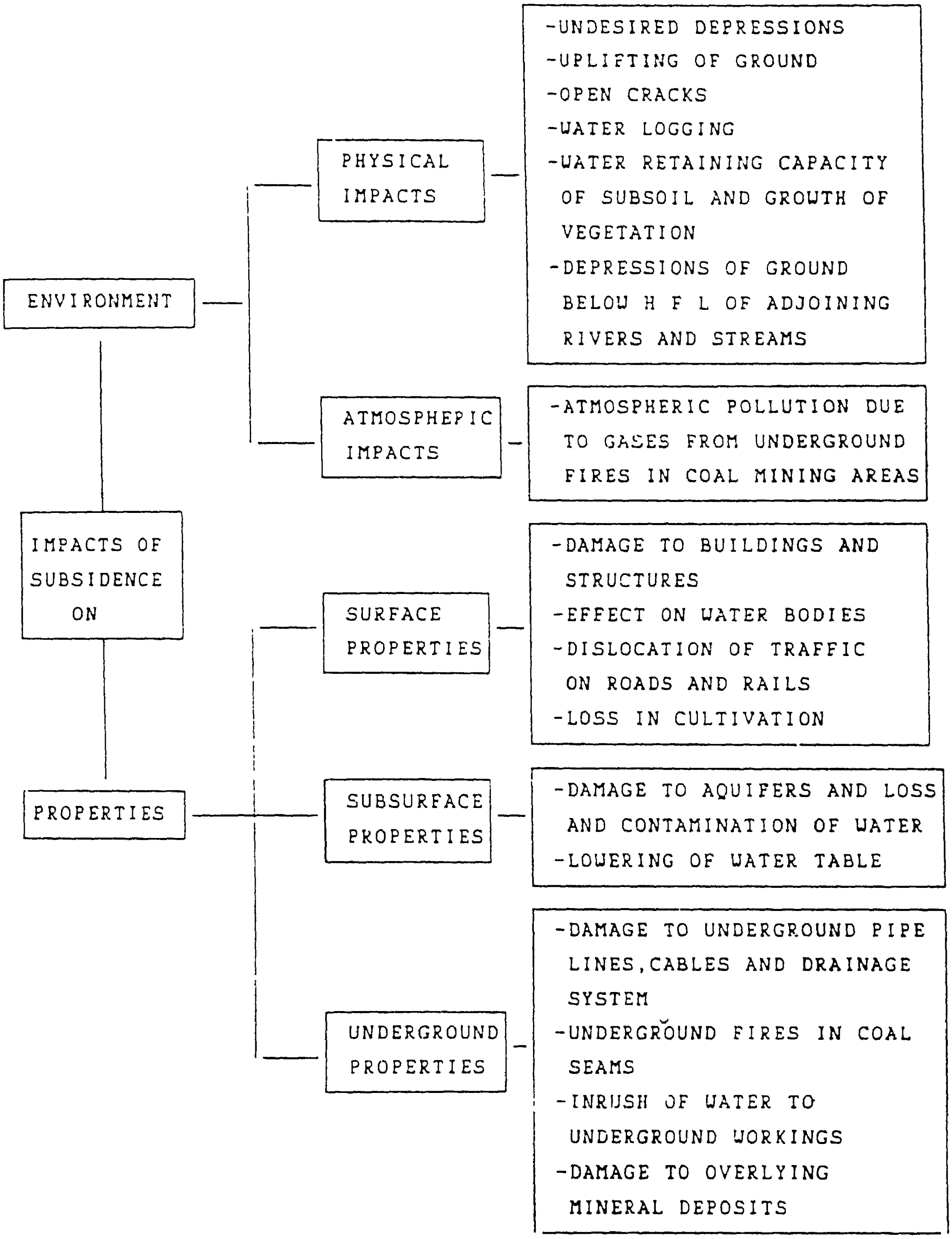

Fig. 2.10 Impacts of subsidence

ABSTRACT

Raniganj coalfield is a major coal producing area, which has facing subsidence problems due to underground coal mining. The occurrence of thick coal seams at shallow depth is the main reason for the subsidence and as a result many coal mines have collapsed in the recent years. In the present thesis, we have made efforts to predict the subsidence occurring in the Indian coal fields in general and in particular to the Raniganj coal field using visco-elastic model. We have made comparative study of the predicted and observed subsidence profiles of Ratibati and Shivadanga coal mines of Raniganj coal field. The results show a reasonable match of the predicted and observed subsidence. We have also studied the effect of various geomining conditions on the subsidence.

3.5.1.1 GEOLOGY:

The Jharia coalfield, about 40 km in length and approximately 12 km in width stretches from west to east and finally turns southward covering an area of about 450 sq. km. It is a sickle shaped coal field occurring in the form of basin and truncated with a major fault, known as boundary fault, on the southern flank. This coalfield is formed of sedimentary rocks of Gondwana group of permian age in Talchir, Barakar, Barren and Raniganj measures (Figure 3.5). Among these, Talchir formation is non-coal bearing and Barren measure is devoid of workable coal seams. The Talchir formation is exposed in patches on the Northern fringe of the coal field out of 450 sq. km. area. The Barakar measures occupy nearly half the area i.e. 218 sq. km. while Raniganj and Barren measures cover 54 sq. km. and 178 sq. km . area, respectively.

The lower Gondwana rocks are well developed here with their basement in metamorphic (Archeans). The general strike of the Gondwana strata is roughly East - West in the Western part of the coal field, which slightly changes in central part to W - NW to S - SE direction. It gradually changes to NW - SE and even N - S in eastern part. The general dip strata is southerly in the northern half which becomes westerly in the eastern part and northerly in the southern part. The dip varies generally between 4 to 5 degrees. The higher dip is mostly in the extreme western part of the coal field (CMRS, 1991). The coal measures of both Raniganj and Barakar series mainly consist of

0.875, 0.875 - 1.325 and 1.325 - 1.875 m are found to be 23.56, 24.98, 17.10 and 6.82, respectively.

The ground movement in black cotton soil due to weather ceases at 3.5 m depth from the surface. The volume expansion ranges from 17 to 34% due to a dominant clay mineral, montmorillonite. The plastic limit of this soil is 49% which does make sun-cracks in dry season. These sun-cracks disappear after absorption of water in rainy season.

3.5.3.2 GEOLOGICAL DISTURBANCE:

A major fault trending N 65° W passing at 12 - 32 m from the top gate road of the long wall panel has 40 m throw at Silewara colliery.

3.5.3.3 HYDROLOGY:

There are three aquifers in Tekadi-Silewara-Patansaongi sub-basin of Kamptee coal field. The top most aquifer, i.e., water-table extends up to the roof of seam V and is composed of sand, Kamthi and upper Barakar sandstones. It contains water-table under phreatic conditions in sand at a depth of 6 - 15 m from the surface. The water movement in the water table aquifer follows the topography of the surface, generally, towards effluent Kanhan river which controls the drainage of the Tekadi- Silewara-Patansaongi sub-basin. The main source of water to the inhabitants is from this aquifer. The middle and lower aquifers are semi-confined and confined in nature.

The precipitation is the main source of recharge of the three aquifers and the average annual rainfall in the area is about 120 cm. The evapo-transpiration, run-off and infiltration expressed in percentage of annual precipitation are 33.3 - 38.3, 40 and 21.6 -

ACKNOWLEDGEMENT

It is my pleasure to express my sincere gratitude to Dr. R P. Singh for his invaluable guidance, motivation and encouragement throughout this work.

I am thankful to Mr. S K. Bhanu, Mr. Bijay Kumar and Dr. N.C. Saxena of C.M.R.S., Dhanbad for their cooperation during the present work.

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The immense patience and untiring struggle of my family members are highly appreciated and remembered.

May, 1993 Ram Naresh Yadav

πR

A table for k_z is prepared graphically for various stages of r/R to calculate the subsidence values.

Sann's method:

Sann's formula for calculating subsidence profile (Bahuguna et al., 1991) :

$$k_z = 2.256 \frac{1}{r} e^{-4e^2}$$

This method predicts as trough with a deeper central area and, therefore, higher values are obtained for partial extractions.

Litwiniszyn's method:

Based on probability considerations, and well supported by field and experimental observation this method has also been verified with the theory of stocharstic rock movements. The formula used is (Whittaker and Reddish, 1989)

$$k_z = \frac{ns}{R^2} \exp[-n\pi(r/R)^2]$$

where n is a constant usually equal to 1. This method has further been modified by Kochmanaski (Bahuguna et al., 1991). Figure 4.4 shows a comparison of various influence zones in graphical form.

The merits of the influence function are:

i) these are applicable to complex mine geometry,

ii) these can be mathematically validated,

iii) these are applicable in various types of mining situation, and

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are as follows:

* a viscosity coefficient μ related to the shear deformation of vertical elements, and

* η a visco-compressibility co-efficient.

Substituting equations 5.2 - 5.4 into equation 5.1, one gets

$$\mu\left(\frac{\partial^3 w}{\partial x^2\,\partial t} + \frac{\partial^3 w}{\partial y^2\,\partial t}\right) - \eta\frac{\partial w}{\partial t} + p\,(x,\,y,\,t) = 0 \tag{5.5a}$$

The load due to overburden is time independent $p = p(x, y)$, therefore, after differentiation of equation 5.5a with respect to t, one gets

$$\frac{\partial^2}{\partial t^2}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} - \lambda^2\right) w = 0 \tag{5.5b}$$

or,

$$\frac{\partial^2}{\partial t^2}(\Delta - \lambda^2)\, w = 0 \tag{5.6}$$

in which Δ is the Laplacian and $\lambda^2 = \frac{\eta}{\mu}$.

Equation 5.6 is the differential equation for the vertical displacement of the ground surface.

The solutions of equation 5.6 are evolved for two different cases (i) for flexible overburden and (ii) for rigid overburden, in order to facilitate proof of the applicability of the preceding theory for different subsidence profiles.

5.2.1 FLEXIBLE OVERBURDEN

For the case of line load $\bar{P}$ along the y axis, $w = w(x, t)$ and equation 5.6 reduces to

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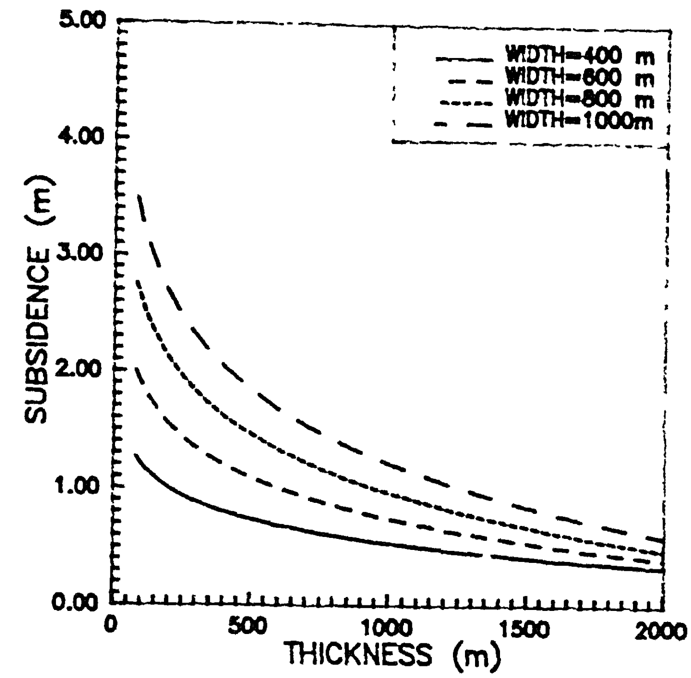
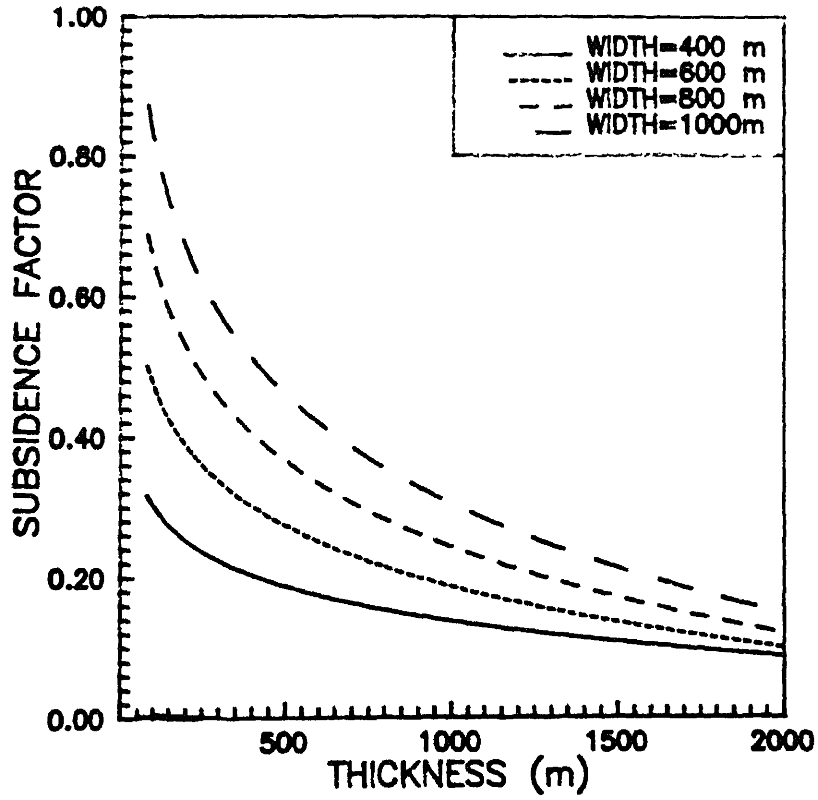
Geomechanics Classification of CMRS, India. Ratings for Parameters

Parameter		Range of Value				
1. Layer thickness	(cm)	<2.5	2.5-7.5	7.5-20	20-50	>50
	Rating	0-4	5-12	13-20	21-26	27-30
2. Structural features	Description	Highly disturbed with faults	Disturbed with numerous slips	Moderately disturbed	Slightly disturbed	Not disturbed
	Rating	0-4	5-10	11-16	17-21	22-25
3. Weatherability (I_{sd-1})	(%)	<60	60-85	85-97	97-99	>99
	Rating	0-3	4-8	9-13	14-17	18-20
4. Strength of the rock	(Kg/cm^2)	<100	100-300	300-600	600-900	>900
	Rating	0-2	5-6	7-10	11-13	14-15
5. Groundwater flow	(mL/min)	>2000	2000-200	200-20	20-0	Dry
	Rating	0-1	2-4	5-7	8-9	10

RMR	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
CLASS	VA	VB	IVA	IVB	IIA	IIB	IIA	IIB	IA	IB
DESCRIPTION	VERY POOR		POOR		FAIR		GOOD		VERY GOOD	



F... 6.6 Variation of subsidence with overburden thickness



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```
      IF(-X)1,1,2
2     WX1(X,T1)=W1(-X,T1)
      W1(X,T1)=WX1(X,T1)
      GO TO 480
1     CC5=AM*X
      CC6=CC3+CC5
      C1=-CC6
      CC7=(2.73**C1)
      WZ1=CC1*CC2/CC4
      WZX=WZ1*CC7
        1=(DB/2)-PWD
      IF(X-DB1)460,460,470
460   W1(X,T1)=WZ1
      GO TO 480
470   W1(X,T1)=WZX*AMT1
      GO TO 480
480   WW1(: ,T1)=-W1(X,T1)
      WK= WW1(X,T1)
      WRITE(*,*)AM,WZ1
      RETURN
      END
      UBROUTINE FLEXIBLE (X1,T11,XK,AM,MEU,NEU)
      COMMON/BLOCK1/P,DB,D1,I1,AMT,PWD
      DIMENSION WX(50,50)
      D11=D1
      D3=0.2458/(D11)
      AM1=D3*AMT
      K=I1
      AM=(AM1)/5
      Y=10.0
      CC1=Y*.00001
      MEU=AM/CC1
      NE =(AM**2)*MEU
      T2=AM*DB
      C1=T11/MEU
      C2=P*C1
```

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CHAPTER I

INTRODUCTION

1.1 GENERAL

The crust of the earth is not rigid, unyielding stratum which we often consider. The crust consists of materials which have properties exactly similar to those of all other solid (and liquid) materials. They react to stress and exhibit strain. They are not immovable, as many natural phenomena clearly show. Therefore, the economic prosperity by the exploitation of the hidden resources in the earth is always accompanied by the punishment of the ground movement, often referred to as subsidence. Subsidence is an inevitable phenomenon and always caused by the withdrawal of ground water, oil and gas. Subsidence due to underground coal mining has been reported from almost all parts of the world. Our country is a major producer of coal. More than 90% of coal mining is carried out by underground Board and Pillar method. In some places of our country, mining has been carried out in igneous rock environment which is known to be quite stable. In such mines if mining excavations are not too large, such rocks are competent enough to support themselves without any subsidence problem. A good deal of mining is carried out deep beneath the surface of the ground. In deeper part, excavations have no

influence at all on the ground surface. The shallow mining operations especially in the low strength rock environment in many coalfields of our country have been facing acute problem of subsidence, especially in Raniganj and Jharia coalfields. It may be anticipated that with the rapidly increasing exploitation of coal, this problem will be further serious. Therefore, in future it will be a major threatening to ecological and environmental balance in the Indian coalfield areas. In past many efforts have been made to understand the mechanism of subsidence, mostly in Developed countries. Many empirical, theoretical as well as physical modelling for subsidence prediction have been carried out. Despite all these efforts and recent advances made in the mining subsidence prediction, it is still not possible to predict subsidence with reliable confidence.

1.2 Purpose of Present Study:

Subsidence due to underground coal mining is an adverse effect which threats ecology and enviornment by land degradation, reduction in vegetation, drop in ground water level affecting forest lands and damage to properties on the surface. Therefore, development of some effective methods for subsidence control are inevitably required. But, subsidence control necessiates a systematic study of subsidence due to underground mining and development of effective techniques for subsidence prediction.

The present study has been carried out to predict the subsidence profiles for Ratibati and Shivadanga coal mines in Raniganj coalfield. The effect of various factors related to geomining conditions have

been studied on the subsidence. The main objectives of this study are:

i. to propose a visco-elastic model for subsidence prediction and study of its parameters,

ii. to predict the subsidence profile,

iii. to study the effect of time on subsidence, and

iv. to study the effect of width, overburden thickness, width and overburden thickness ratio on subsidence and subsidence factor.

1.3 Scope and Method of Study:

In the present study emphasis has been laid on the prediction of subsidence profiles due to underground coal mining in Indian coalfields. A visco-elastic model has been considered for subsidence prediction in Indian coalfields. The validation of the model has been done by taking parameters and observed values from Ratibati and Shivadanga coal mines of Raniganj coalfield. The subsidence profiles for these coal mines have been predicted and effects of various factors on subsidence have been studied.

1.4 Organization of thesis work

This thesis has been divided into seven chapters. Besides this introductory chapter, chapter II deals with causes and impacts of

subsidence. Chapter III describes about the underground coal mining in India. Chapter IV deals with the present status of subsidence prediction. Chapter V describes the proposed visco-elastic model with its parameters. Results and discussion of the present study have been included in Chapter VI. Thesis documentation ends, with conclusion of thesis work and recommendation for further work in Chapter VII. The computer program developed and used in the present study has been appended at the end.

CHAPTER II

SUBSIDENCE: CAUSES AND IMPACTS

2.1 INTRODUCTION

Subsidence is defined as the downward movement of the ground surface. The effect of the subsidence is seen in the form of structure settling into the ground or lowering of ground itself and carrying the structure with it, or even a surface layer collapsing into an underground cavity. Subsidence usually refers to vertical displacement of a point, but also implies a measure of horizontal movement of adjacent points by virtue of the lateral shift of ground generated by the accompanying downward movement.

Subsidence of the surface commonly refers to en masse lowering of the ground rather than the localised effect of consolidation or shrinkage of soils. Such sinking of the surface may arise from various natural and man-made activities. Subsidence processes are concealed below ground and their development to the point of surface depends upon the nature of displacement mechanism. Sometime more than one effect of subsidence occurrence is present and it requires consideration in analysing the causes of subsidence.

2.2 CAUSES OF SUBSIDENCE

Subsidence of the land surface may arise from regional geology

due to tectonic or volcanic activities, from removal of material from underground such as withdrawl of fluid or material such as tunneling and mining operations, and from localized natural causes such as sinkhole formation or underground erosion or lateral flow of sub-soil (Whittaker and Reddish, 1989). The subsidence have been broadly classified into two categories namely, (i) natural and (ii) man-made. Genetic and activity wise classifications of causes of subsidence have been given in Figure 2.1 (Mishra, 1991).

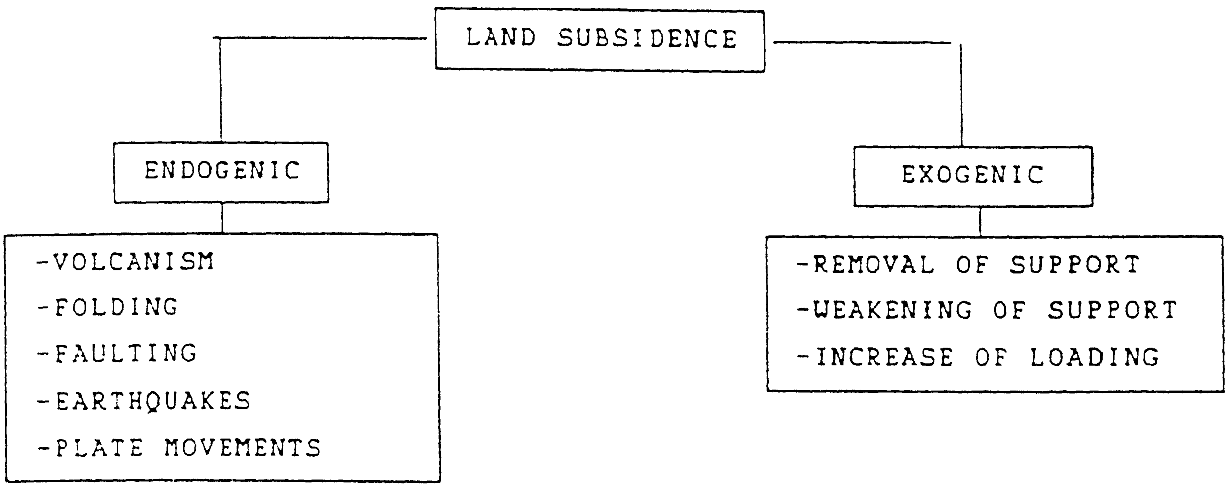
2.2.1 SUBSIDENCE DUE TO SURFACE SOLUTIONS

The occurrence of sink-holes and crown holes in limestone deposits is probably the most common form of natural subsidence. The phenomena frequently occur where carbonate rocks, rock salt, and gypsum deposits lie relatively close to the surface. The formations of subterranean voids in such rocks by solution action creates the conditions favoring subsequent collapse and/or widening by washing down of overlying material thereby resulting in sink-hole or crown-holes.

Among the common soluble earth materials rock salt is the most soluble but because of its limited occurrence in the nature it is now rarely associated with surface subsidence under natural conditions. The formation of deep crater of 0.60 m diameter in south central Kansas in USA is the classical example of subsidence occurrence in salt deposits (Poland, 1984).

Gypsum is a rock forming mineral which is found abundantly in

1 GENETIC CLASSIFICATION OF LAND SUBSIDENCE



2. ACTIVITY WISE CLASSIFICATION

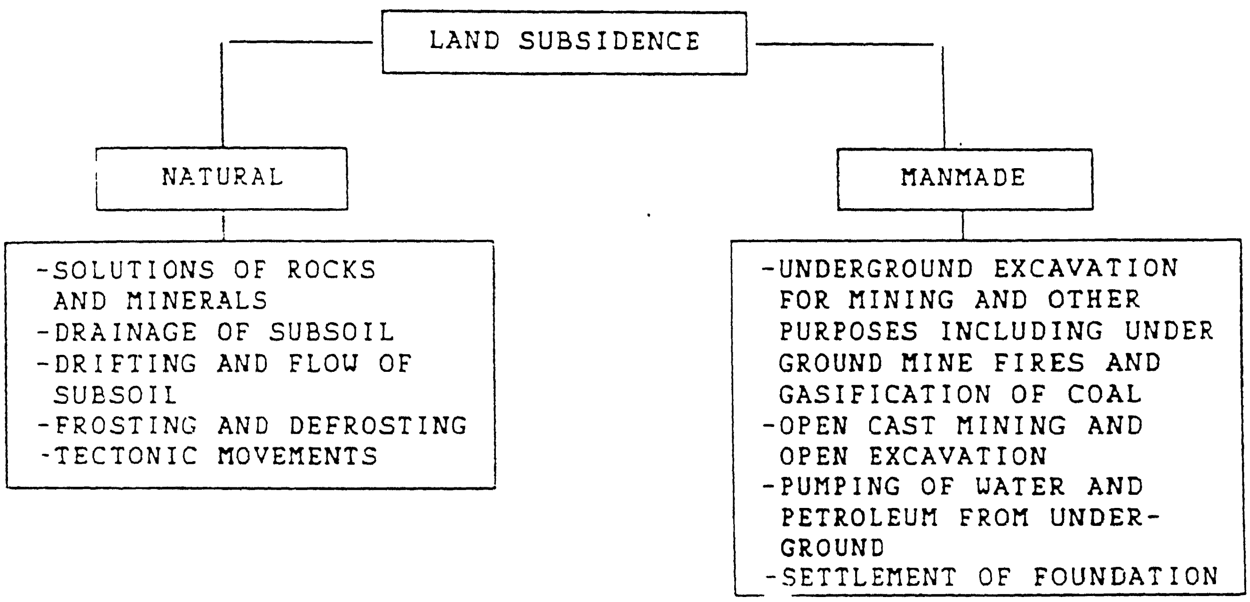


Fig. 2.1 Classification of subsidence

marine evaporite basin deposits. The evidence of surface subsidence, caused by solution of gypsum is present in Rosewell basin in New Mexico. Sinkholes on the land surface have been reported in areas underlain by gypsum bearing rocks in New Mexico.

The carbonate rocks, limestone and dolomite are responsible for the most widespread incidence of subsidence related to solution because of its wide geographic distribution. Foose (1968) has observed the effect of dewatering of underground mines in carbonate terrain on subsidence.

2.2.2 SUBSIDENCE DUE TO SUBSURFACE MECHANICAL EROSION

Development of subsurface flow channels in unconsolidated deposits causes subsurface mechanical erosion. Water, which transports grains of silt and sand, finds an outlet along a valley wall or cliff face or internally in caves, mine openings or boreholes. Erosion tends to increase headward from the outlet, creating or enlarging a tunnel. The enlargement of tunnel reduces the support capacity of surface materials causing the ground surface to collapse, forming sink-hole. In order to produce surface subsidence, the subsurface erosion mechanism requires three conditions (Allen, 1969):

(i) a previous easily available material overlain by sufficient hard material to form a roof above the developing tunnel,

(ii) water with sufficient head to transport grains of erodible material, and

(iii)availability of outlet for disposal of the flowing water and the transported sediment grains.

Example of subsidence attributed to subsurface erosion is present in Kanus, China. Tunnels up to 1 m wide and 3 m high formed due to piping in Loess deposits (Poland, 1984).

2.2.3 LATERAL FLOW AS A SUBSIDENCE MECHANISM

Subsidence as a result of lateral flow of subsurface materials have been reported both under natural geologic conditions and under loading by man-made activities (Allen, 1969). The common earth materials susceptible to plastic flow are salt, gypsum, clay and shale. The example of subsidence by salt flow is present in the paradox basin in Utah and Colarado in USA. Subsidence features as a result of flow of shale are present in the jurassic iron or locality in east central England. Lateral flow on thick glacial clay deposits in the great lakes region of North America has lowered the ground surface by nearly 2 meters (Terzaghi, 1953).

2.2.4 ROLE OF COMPACTION ON SUBSIDENCE

Compaction as a cause of subsidence occurs both naturally and by man-made activities. Subsidence takes place as a result of reduction in the volume of low-density sedimentary deposits that accompanies the process of compaction, in which particles become more closely packed and the amount of pore space is reduced. Compaction may be induced by loading, drainage, vibration, extraction of pore fluids and

hydrocompaction. The magnitude of subsidence due to compaction is a function of the relative amount of pore space in the material as originally deposited, the effectiveness of the compacting mechanism, and the thickness of the deposit undergoing compaction. Natural deposits of high initial porosity such a undisturbed loess, delta, and peat are more susceptible to subsidence as a result of compaction.

2.2.4.1 LOADING

Natural loading is very effective where great thickness of fine grained sediments accumulated rapidly. Subsidence results due to compaction of unconsolidated sediments. The lower delta of Mississippi river subsided by 6 m due to the deposition of 300 to 500 million ton of sediment every year (Poland, 1984).

2.2.4.2 DRAINAGE

Lowering of the water table by artificial drainage stimulates compaction of sediments in the low-lying areas causing subsidence of the surface. Compaction rates are higher in the areas of Peat and Polders because of extreme volume change upon drying. The largest Peat areas in the United States that are subsiding are in the Florida Everglade region.

2.2.4.3 VIBRATION

Unconsolidated sedimentary deposits can be compacted by vibration

under natural conditions during earthquakes. surface structures on saturated alluvium or uncompacted fill may subside or settle differentially in response to earthquake vibrations. If the foundations lie on a hard stratum, the structure may appear to rise as the surrounding sediments subside by compaction. A variety of man-made sources of vibration include heavy rock crushing equipment, pile driving, blasting an elevated railway and turbo generators. Underground nuclear explosions in unconsolidated material are characterized by craters on the ground surface.

2.2.4.4 EXPLOITATION OF PORE FLUID

Subsidence caused by the withdrawal of fluids is rarely sudden. Although, the process starts from before but it is difficult to observe since the rate is very slow. Its effect can be significantly seen through an existing structure in the region. Such subsidence was noticed when the subsidence reached a total of 7.8 m at the centre of an area of 5200 ha, which was affected significantly. Such subsidence create serious problems than those subsidence due to the mining of solid materials. It is a problem of current importance in many parts of the world. Inevitably, it will continue and will become more serious in future with the increasing demand for water and energy resources such as gas and oil.

The basic mechanism of subsidence is simple and its individual details are generally complex. When subsidence fluids are extracted, the surrounding ground tend to readjust itself with the changes of

pressure. The underground pressure are operative in holding apart individual particles of silt or clay, its release may permit such a redistribution of underground stress that the clay will begin to consolidate with a consequent decrease in volume. In these and other ways, the very slow movements associated with consolidation eventually reach the ground surface as subsidence.

2.2.4.5 HYDROCOMPACTION

Subsidence due to ground water withdrawal is generally attributed to slow consolidation of sediments due to increasing effective stress. However, under certain geologic condition, ground water lowering can create conditions for collapse on subsequent inundation. This is possible in the case of structurally unstable soil. Yudhbir (1984) described the collapsible behavior of residual soils. Henkel (1982) has illustrated an example of catastrophic collapse resulting from ground water lowering in dolomite or limestone rocks in South Africa. The reduction in strength on wetting in clay and salt bonded soil may result from reduction in inter bonds due to the advent of water. The process, formed "hydrocompaction", produces rapid and irregular subsidence on the ground surface, ranging from 1 m to 5 m.

2.2.5 SUBSIDENCE DUE TO TECTONIC AND VOLCANIC ACTIVITIES

Large areas of considerable downward displacement have been associated with a few earthquakes of large magnitude. Deltaic deposits are particularly prone to sinking due to earthquake effects sometimes causing liquefaction of sand deposits. Areas adjacent to major faults

may experience the effects of subsidence during earthquake. Earthquake in Montana in 1959 has produced the maximum subsidence of 6.6 m in an area of 1600 km^2 (Poland, 1984). Volcanic deposits exhibit surface subsidence due to collapse of void structures.

2.2.6 SUBSIDENCE DUE TO UNDERGROUND FIRE

Underground fires in coal seams cause subsidence movements because fire consumes coal which amounts to extraction of coal by fire. The only component to coal not consumed by fire is ash, which remains in the seams. The nature and magnitude of subsidence movements due to underground fires depend upon the following factors:

* thickness of seam,
* percentage of ash in the coal,
* percentage of carboniferous material in rock mass in immediate vicinity of coal seam,
* depth of seam on fire, and
* size of area consumed by fire.

A detailed accounts of the mine fires have revealed that it was due to either man-made near the outcrop quarries or it was due to breathing of air in caved areas through subsided zones.

2.2.7 SUBSIDENCE DUE TO UNDERGROUND MINING

Mining subsidence is a general term to describe vertical and horizontal movements caused at surface by the removal of coal or other minerals at a depth excavation. The strata comprising the earth's crust are subjected to two main natural forces, namely vertical and

lateral compressive forces. Both of these can, normally be considered as being in equilibrium (in a state of balance). The general effect of mining is to create a space into which the overlying strata tend to subside and break down. In this way the normal state of equilibrium is disturbed, and there are vertical and lateral movements in the strata, which ultimately transmit themselves to the overlying surface. These movements will continue until the space has been closed and all the forces have been redistributed and equilibrium restored. The general tendency of the strata movement is inwards and downwards towards new centre of gravity in the area of excavation. Thus, the strata over the undisturbed coal is also affected and is drawn towards the workings.

The subsidence phenomenon is shown in Figures 2.2 (Halbaum, 1903). Figure 2.3 shows a more general scientific representation of subsidence in terms of graphs along a transverse section. Figure 2.3 (a) shows a subsidence profile,Figure 2.3 (b) shows a strain profile , and Figure 2.3 (c) a displacement profile. The subsidence profile represents the vertical component of the movement above the long wall panel being at a maximum over the centre of the panel. The strain profile represents the relative change in length of the surface over the panel, the surface extending over the rib sides and shortening over the panel centre.

The displacement profile represents the horizontal component of the movement over the panel, movement being towards the panel centre and at a maximum in the region of the rib sides. The characteristics of a general subsidence due to coal mining have been outlined above,

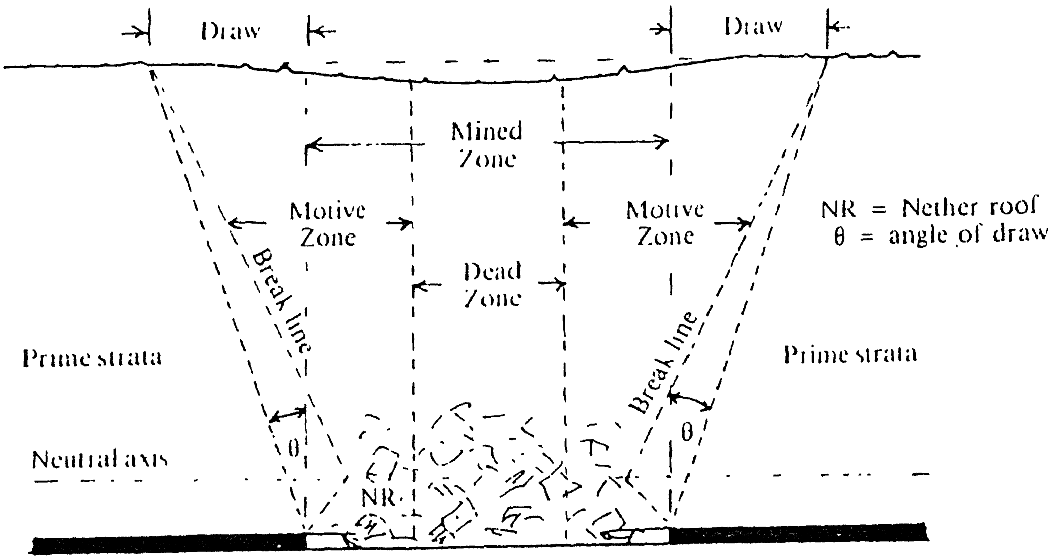


Fig. 2.2 Mining subsidence representation and terminology

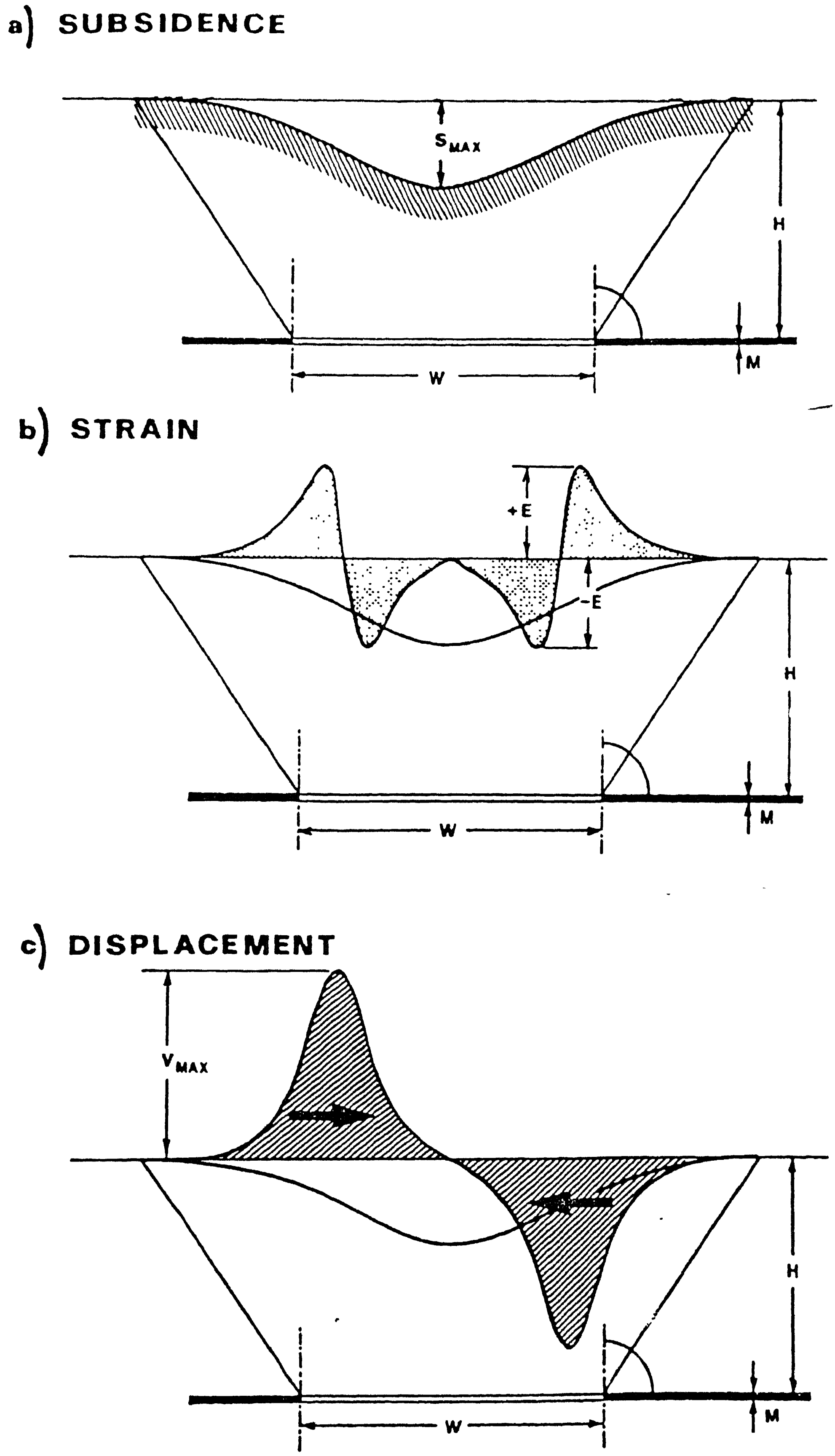


Fig. 2.3 Scientific representation of subsidence

but many other factors can change the significance of this basic movement in actual mining situations. These factors are described in the next section.

2.2.8 FACTORS AFFECTING MINING SUBSIDENCE

The magnitude and nature of mining subsidence and damage caused by it depend upon the following three factors:

* mining,
* site, and
* structural factors.

Mining factors consist of the mining methods and physical dimensions. Site factors consist of the local geological environment and structural factors consist of the nature of the structure in terms of its sensitivity to damage.

2.2.8.1 MINING FACTORS

The mining factors are probably the most important factors as these provide the major parameters for prediction purposes essentially consisting of the excavations physical dimensions. The mining factors have the greatest single influence on the resulting damage. Various mining factors which has influence on the subsidence are discussed in the following section.

a. MINING DEPTH

The depth of mining has a direct influence upon the magnitude and distribution of surface effects. Since all other factors are constant therefore an increase in depth results in a reduction in the magnitude

of movement spread over a greater area.

b. MINING THICKNESS

Greater the excavation thickness greater the associated surface movements and vice-versa.

c. MINING PANEL WIDTH

The subsidence movements start after a certain width has been extracted underground and thereafter they increase with the width of extraction till critical width is reached.

d. PANEL LENGTH

If a long wall panel's longitudinal travel before stopping is relatively short compared to depth, then the resulting subsidence can be expected to be greatly reduced compared to similar panels with appreciably greater travel.

e. SURFACE SLOPE AND SEAM DIP

Both surface slope and seam dip can alter the magnitude and particularly the position and shape of a subsidence in relation to the excavation. Generally, the area of movement is thrown down dip of the excavation. It is illustrated by Figure 2.4 (Whittaker and Reddish, 1989).

f. MINING METHOD

The use of stowing or packing in the mining method can help to reduce surface subsidence considerably.

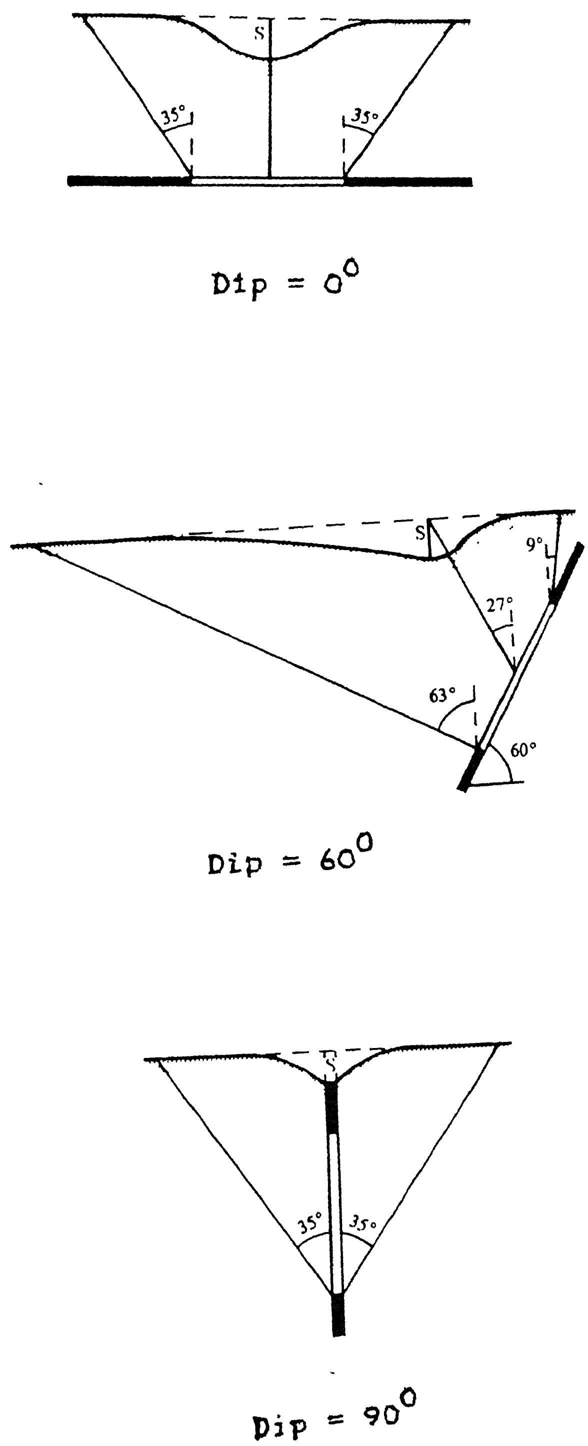


Fig. 2.4 Subsidence profiles over dipping seams

g. TIME

For most purposes mining subsidence can be considered instantaneous, however, continuing movements up to 10 percent of maximum subsidence can take place over the following two years. Structures may continue to be damaged due to other factors such as weathering of the foundation, damaged drains etc, giving the impression of time dependent effects.

2.2.8.2 SITE FACTORS

Site factors, in many cases, results in the actual subsidence differing from that predicted. The effect upon structures of site factors is rarely predicted because of the expense of a detailed site investigation. It is important however, to consider the anomalies that they cause, the main factors are as follows:

a. NEAR SURFACE ROCK TYPE AND STRUCTURE

Rocks such as mudstone and clay will bend uniformly under the influence of subsidence giving an even distribution of surface strain. Conversely sandstones and limestones with well developed jointing systems can behave in an uneven manner with strains concentrating across particular joints and individual blocks tilting by difference amounts (Figure 2.5).

b. FAULTS

Faults represent a major weakness in the surface and as such are sometimes exploited by ground movements resulting in concentrated

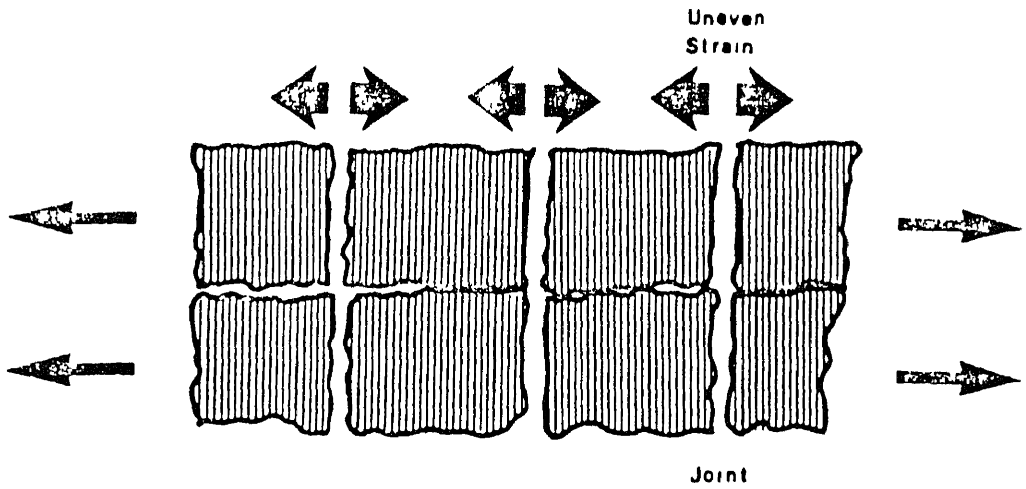


Fig. 2.5 Effect of joints on subsidence

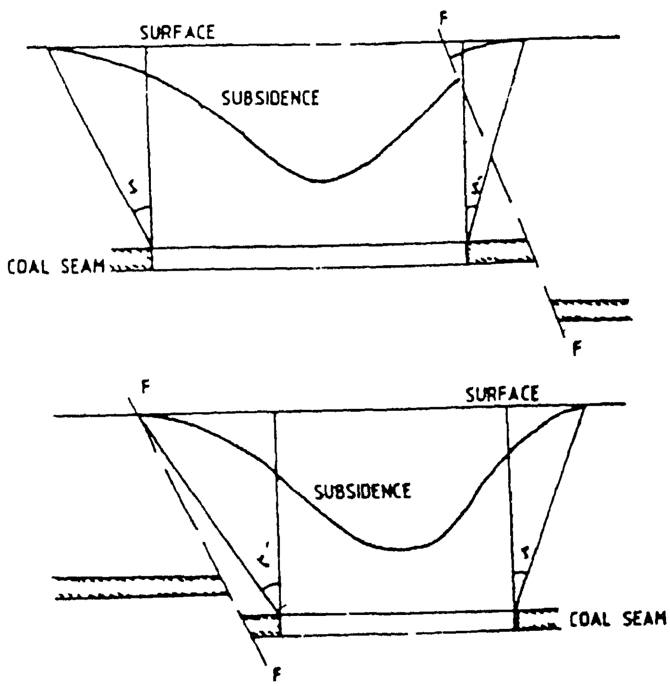


Fig. 2.6 Effect of fault on subsidence

surface strain and stepping. Themost likely configuration for fault movement consists of working closely under the hade of a fault and parallel to the fault. Presence of faults in the vicinity of panels tend to arrest as well as extend the area of subsidence (Figure 2.6).

c. UNSTABLE NATURAL FEATURES

Unstable or marginally stable hillsides, cliffs and caves have been known to fail due to the changes induced in the surface by mining, both direct physical changes such as tilt and indirect alterations in the local hydrology can lead to instability.

d. HIDDEN MAN MADE FEATURES

Old quarries, rubbish tips, shafts and river beds can all cause a local concentration of movement, as material consolidates in an uneven manner.

e. OVERLYING OR PREVIOUS WORK

Many coalfields, specially in India, have multiple number of seams. The subsidence due to extraction of multiple seams is due to combined influence of extraction of all the seams (Figure 2.7).

The effect of extraction of lower seams is generally more pronounced because the strata overlying upper seams gets disturbed and subsides during their extraction. Figure 2.8 shows the effect of overlying, underlying and sidewise previous workings on subsidence. Figure 2.9 shows subsidence due to multi-lift extraction in which the magnitude of subsidence due to second and third slice could be nearly

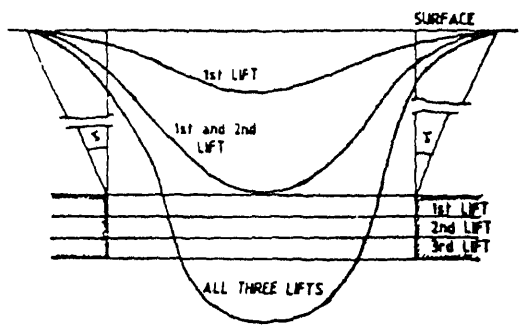


Fig. 2.9 Subsidence due to multi lift extraction

equal to their extraction thickness.

i. IMPACT OF SUBSIDENCE

Mining subsidence, initiated due to readjustments of overlying strata of an underground excavation, produces tension and compression at surface and differential movement in the earth crust. These phenomena when exceeds certain limit gives birth to cracks, fissures and ditches at the top extending downwards through the strata, and hazards to environment and ecology by disturbing ground water level, surface hydrology, decreased crops, destabilising surface structures. Thus, social economy and confidence, face a major set back.

The impact of subsidence on day to day life depend upon the nature, magnitude, and extent of movements. The various impacts of subsidence have been shown in Figure 2.10 (Mishra, 1991). The widespread damaging effects of subsidence occur mainly due to cracks produced by differential movements in the earth crust and change in slope of the surface.

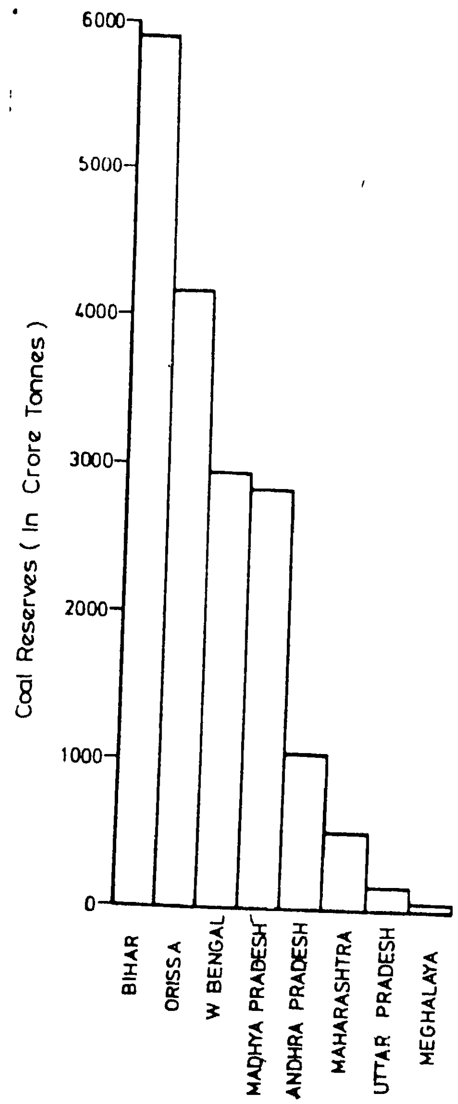


Fig. 3.1 Spatial pattern of the coal reserves in India

3.3 LOCATION OF INDIAN COALFIELDS

The major coalfields in India are :

- Raniganj,
- Jharia,
- East Bokaro and West Bokaro,
- Panch-kanhan and Tawa valley
- Singrauli,
- Talcher,
- Chanda-Wardha,
- Godavari valley,
- Karnpura and others.

Figure 3.2 shows the location of major coalfields. The coalfields are widely spread from west to east (Gujarat to Assam) and north to south (Kashmir to Tamil Nadu) (CMRS, 1991).

3.4 GEOMINING CONDITIONS

The geomining conditions of Indian coalfields from subsidence point of view, can be summarised as follows (Saxena et al., 1989):

3.4.1 Depth: The depth of underground workings varies from about 15 m to 800 m. The average depth of underground workings may be about 250 m. Only a few collieries have working depth of more than 400 m.

3.4.2 Extraction thickness:

In general the extraction thickness ranges between 2 m and 3 m. Coal seam less than 0.9 m in thickness are considered unworkable. The maximum extraction thickness in one lift is of the order of 4 - 5

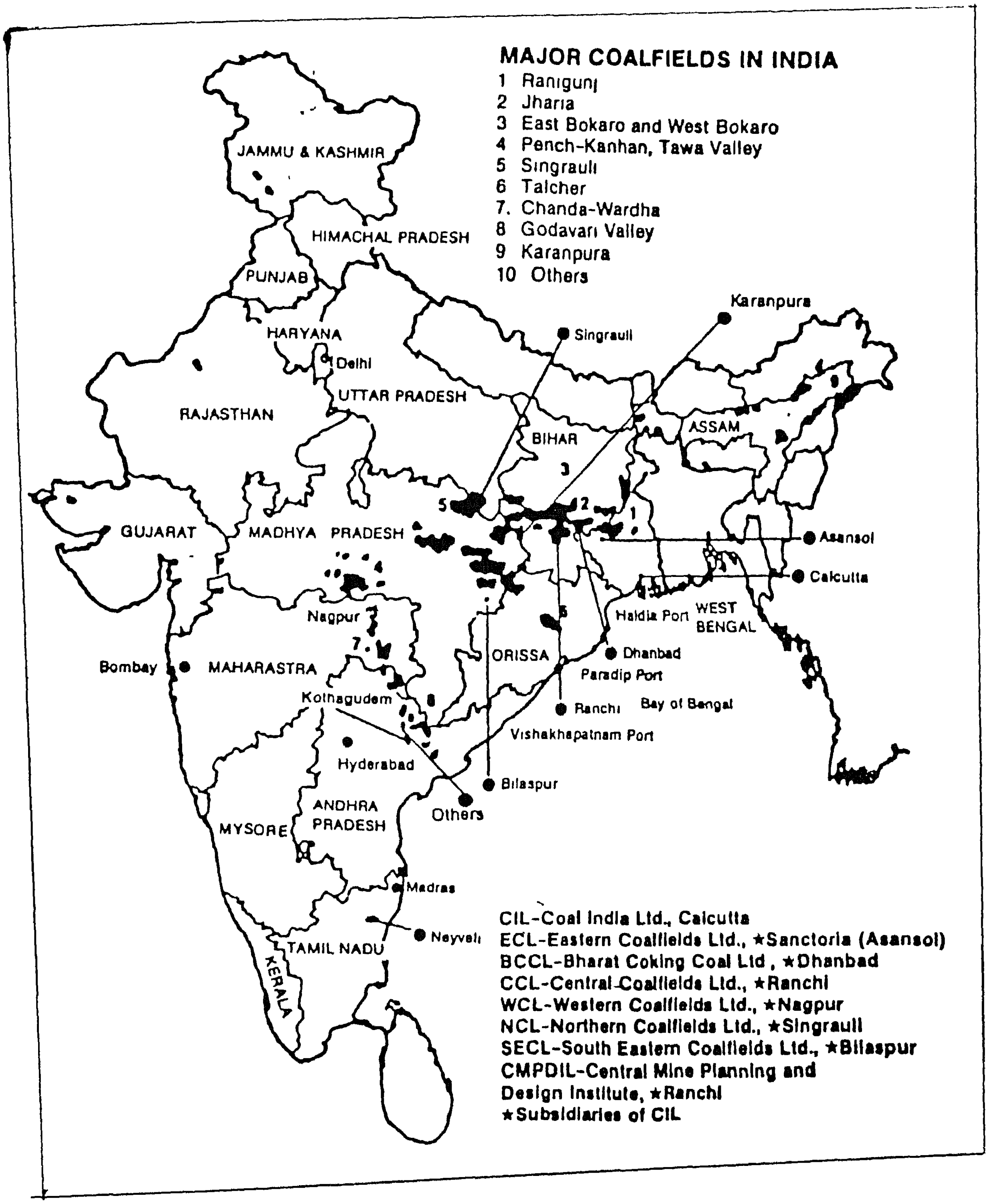


Fig 3.2- Location of major Indian coalfields

3.4.3 Method of extraction

The mining methods used for the coal mining are (Kratzsch, 1983):

3.4.3.1 Board and Pillar method:

This method with variations contribute about 90% of coal production from underground. In this method, parts of the deposits are left standing between the working fronts (the stopes) to safeguard against movement of the overlying rock during mining. The basic principle of this system is the systematic extraction of minerals from either naturally or artificially supported rooms with the transfer of cover loading to coal pillars which are an integral feature of this system of mining. The rooms are generally supported, if not free standing, for the duration of mining operations. The pillars are actually designed for effective support of the overburden. Figure 3.3 shows the layout of Board and Pillar method which is very common method of coal mining in India.

3.4.3.2 Long Wall Method:

Long wall mining (Figure 3.4) is the method of total extraction principally employed in the European Coal Mining Industry. The "long wall" is the working face, which may be anything up to 300 m long and depending on mining progress, may advance laterally towards the mine boundary by several meters a day. The narrow opens trip or "face working", between the "goaf" the mined out seam and the coal face is protected against roof falls by an array of vertical props capped with horizontal bars, or by composite supports having broad roof canopies coal is both won from the face and transferred to the conveyor mechanically.

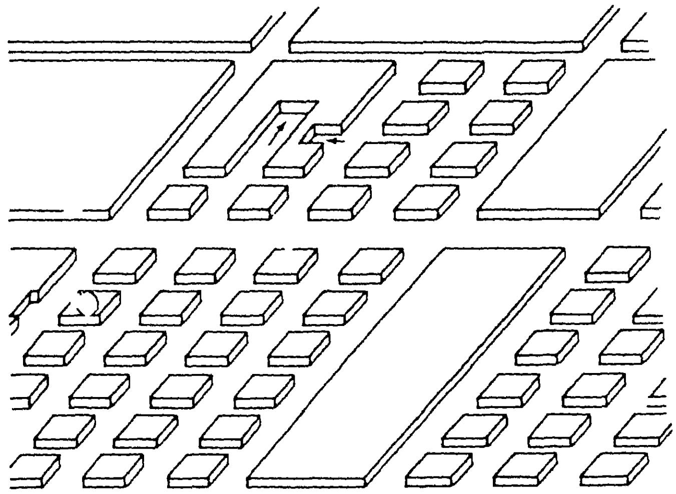


Fig. 3.3 Layout of Board and Pillar method

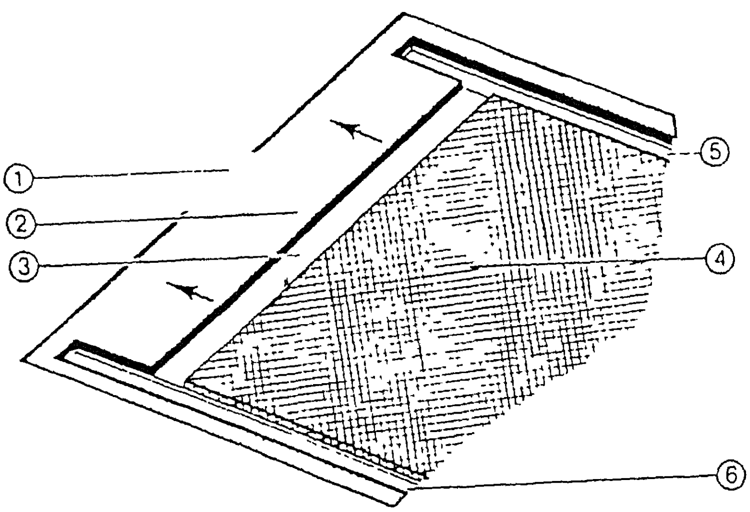


Fig. 3.4 Layout of longwall mining method

The newly mined and abandoned strip behind the face working must be filled immediately, and when mining makes good progress, perhaps advancing by as much as 5 m a day can cause technical problems. The solution to such problems is to employ pneumatic stowing, blowing in waste through special pipes. The "gate roads" leading on either side of the goaf to each end of the working face the "top" and "bottom" road, respectively serve for ventilation, haulage, and man riding. In steeply dipping seams the working face is set at an angle to the gate roads to reduce the gradient.

Long wall mining is thus, characterized by the long working front, the large area worked at a time, and the rapid extraction of the seam. The disturbed rock mass comes to rest again within 1 to 3 years of mining, leaving a flat trough at the surface.

3.4.3.3 Stowing:

The lowering of roof on the fresh support is known as stowing. In this procedure, the mine excavation is filled with crushed rock or other waste material to support the roof artificially as it goes down, so that it will settle almost without a break. The presence of stowing material support reduces the degree of sagging and of opening up in the bonds between overlying layers. This technique can be applied to room-and-pillar, long wall, and short wall working.

3.4.3.4 Caving the roof:

In the caving method, the roof of the mined-out and abandoned working area is systematically caused to collapse. In order to avoid leaving large cavities with projecting slabs which could suddenly fall

and endanger further working. The plan is that the immediate roof layer breaks off in large lumps and fills the mine excavation as a heap of rubble - so - called self stowing medium which provides a yielding underlay for the main mass of overlying rock. The latter then sags almost unbroken on to this and settles without subsidence delay directly behind the working front.

3.4.4 Coal Measures:

The Indian coal measures mainly consist of sandstones, shales, coal, clays and soil. The sandstones, fine to coarse grained, are bedded as well as massive and their percentage varies from about 60 to 90. Many coal fields in central India have black cotton soil also.

3.4.5 Number of Coal Seams:

Most of the Indian coalfields have multiple number of coal seams in close proximity. The maximum number of coal seams available in a coalfield is about 40. In most of the coal fields multi-seam mining is carried out.

3.4.6 Unapproachable old workings:

Many Indian coalfields have waterlogged/dry unapproachable underground workings, many of which have collapsed in recent past. Due to collapse of coal mines subsidence has occurred which has damaged surface properties.

3.4.7 Geological disturbances:

The subsidence in coalfields can cause disturbance to the geological structures which are prevalent in the coal fields. The common geological structures found in coalfields are faults and

joints.

3.4.8 Dip:

The coal seams in most of the coalfields are flat. Some areas in the outskirts of Jharia coalfields and in Assam have semi-steep to steeply dipping seams.

3.5 Coal Mine Subsidence:

The subsidence in coalfields is quite common throughout the world. The details of some Indian coalfields, which are facing the problem of subsidence, are given below:

3.5.1 Jharia Coal Field (JCF):

Jharia coal field is the only coal field producing prime coking coal in India. This coal field is located in Dhanbad district of Bihar and lies between latitude 23° 39' N to 23° 48' N and longitude 86° 11' E to 86° 27'E. Jharia coal field has a long mining history dating back to 1890 and it is the most extensively exploited coal field in the country because of its metallurgical grade coal reserves.

The ground elevations of the field generally vary between 240 m in the Western part to 140 m in the South Eastern part. The peripheral region of the coal field is characterised by occurrence of small sandstone ridges and rather uneven topography. The topography of the coal field has been considerably obliterated due to surface subsidence, surface mining, overburden dumping and fires, etc. The local elevations and depressions are the characteristic of this coal field.

sandstone and shales. The average composition of coal measures is shown in Figure 3.6 (Prasad, 1989).

3.5.1.2 LAND DEGRADATION:

Extraction of thick seams by caving in past at shallow depths has damaged the ground surface in the form of subsidence and formation of cracks reaching up to the surface, enhancing the chances of spontaneous heating of coal seams, have caused mine fires. The Jharia coal field has faced 70 times mine fire spread over in an area of 17.32 sq. km. Only 4.32 sq. km. fire falls in the vicinity of proposed underground mining blocks zone.

In Jharia coal field, the practice of coal mining by underground mining started in the beginning of the twentieth century and is still practiced. The Board and Pillar method of underground mining is very common. This method is used in more than 90% underground mines. Due to availability of thick and continuous seam in close proximity, multi-seam working and existence of large number of surface properties, almost all the underground mines have been facing subsidence problems. The problems of subsidence is both gigantic and multifarious. In Jharia coal field, about 57% area is covered by subsided grounds, fire areas, overburden dumps and abandoned quarries. Out of total 57% area, 60% of it (i.e. 33% area of the surface right of JCF) is subsided land. The subsidence is attributed to the underground mining process in JCF (Prasad, 1989).

3.5.2 RANIGANJ COALFIELD (RCF):

Raniganj coalfield is one of the main sources of coking coal, has

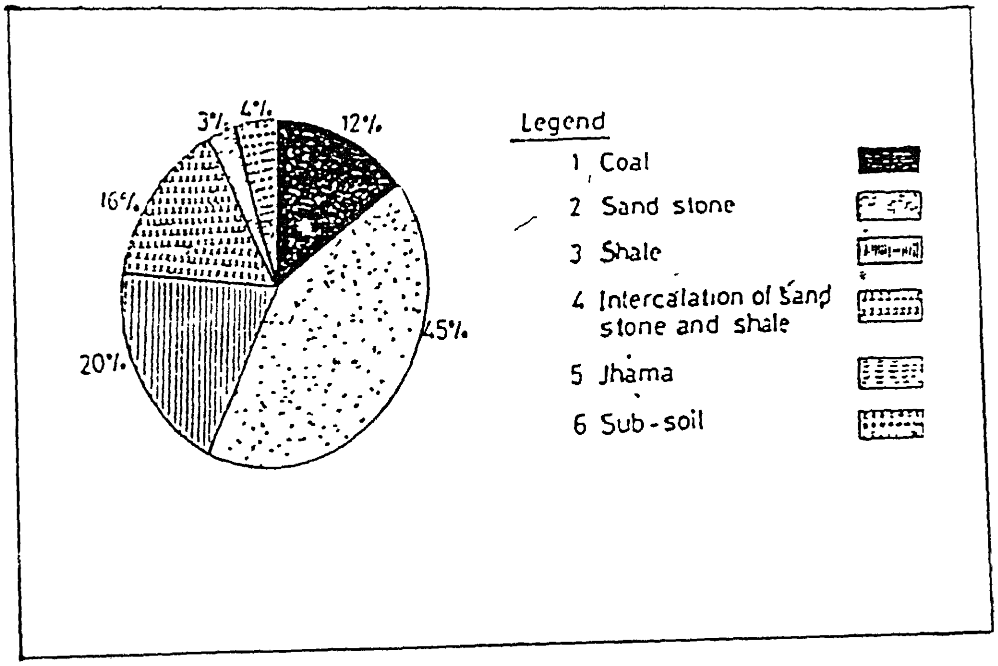


Fig. 3.6 Average composition of coal measures of Jharia Coalfield

been facing significant problems as a result of underground coal mining. Raniganj coalfield (Figure 3.7) lies mainly in Burdwan district of west Bengal and Dhanbad district of Bihar. The coal field lies between latitudes $23^{\circ} 33' N$ and $23^{\circ} 52' N$ and longitudes $86^{\circ} 28' E$ and $86^{\circ} 38' E$. It is about 170 km from Calcutta towards west and 1240 km from Delhi towards east. This coal field is also well connected with steel plant like Bokaro, Durgapur, Burnpur, Tatangar, Rourkela and Bhilai by rail and is dipping at 5°.

The coal in this region is mainly from the lower Gondwana group, which is underlain the metamorphics. The colliery is situated approximately 12 km south-east of Asansol in the Eastern coalfields limited (ECL) and is a subsidiary of coal India. The average thickness of extracted seam is 3.38 m and the overburden ranges from 20 m in the north to 50 m in the south. The extraction of seam is being done using Board and Pillar method .The panel size being 120 m along the strike and 210 m along the dip. The coal pillars size varies between 20 and 24 m and the galleries width between 4 and 4.8 m. The seam is extracted by drilling and blasting using timber props. The immediate roof of the Nigha seam consisted of coal, shale and sandstone of various ascending order. The strata of the overlying rocks is shown in Figure 3.8 and the average composition of coal measures, on the basis of the bore-hole section, is shown in Figure 3.9 (Krishna, 1989). The surface topography of Raniganj coal field is considered to be flat with gentle slopes.

Raniganj coalfield, above 75 km in length from east to west has

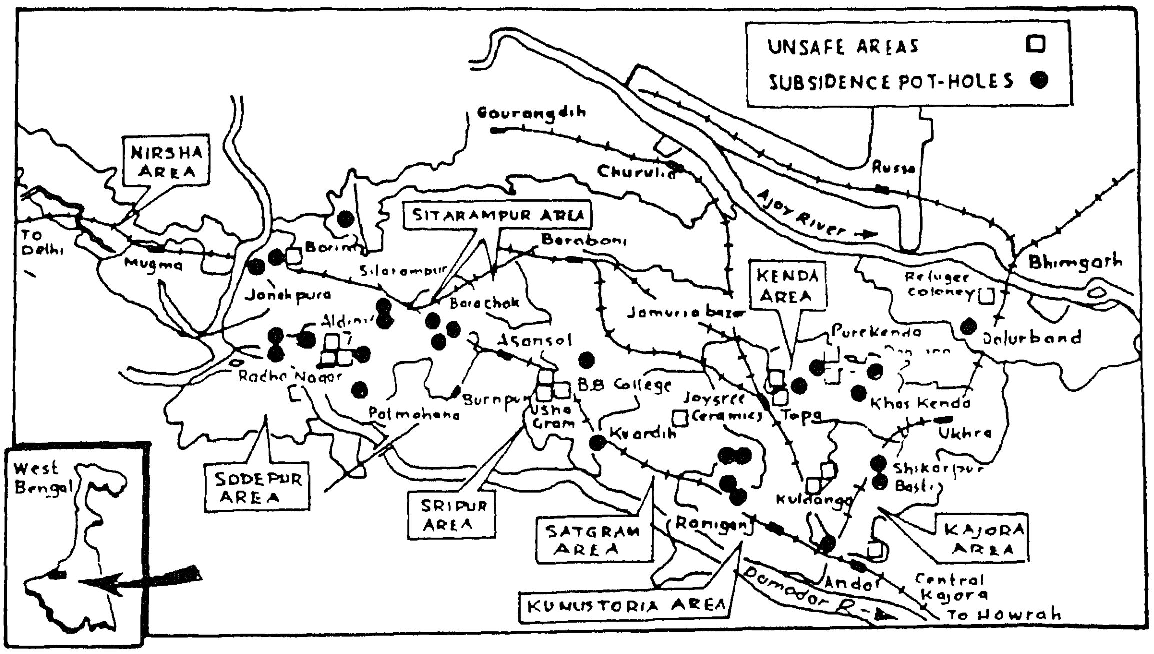


Fig. 3.7 Location map of Raniganj coalfield

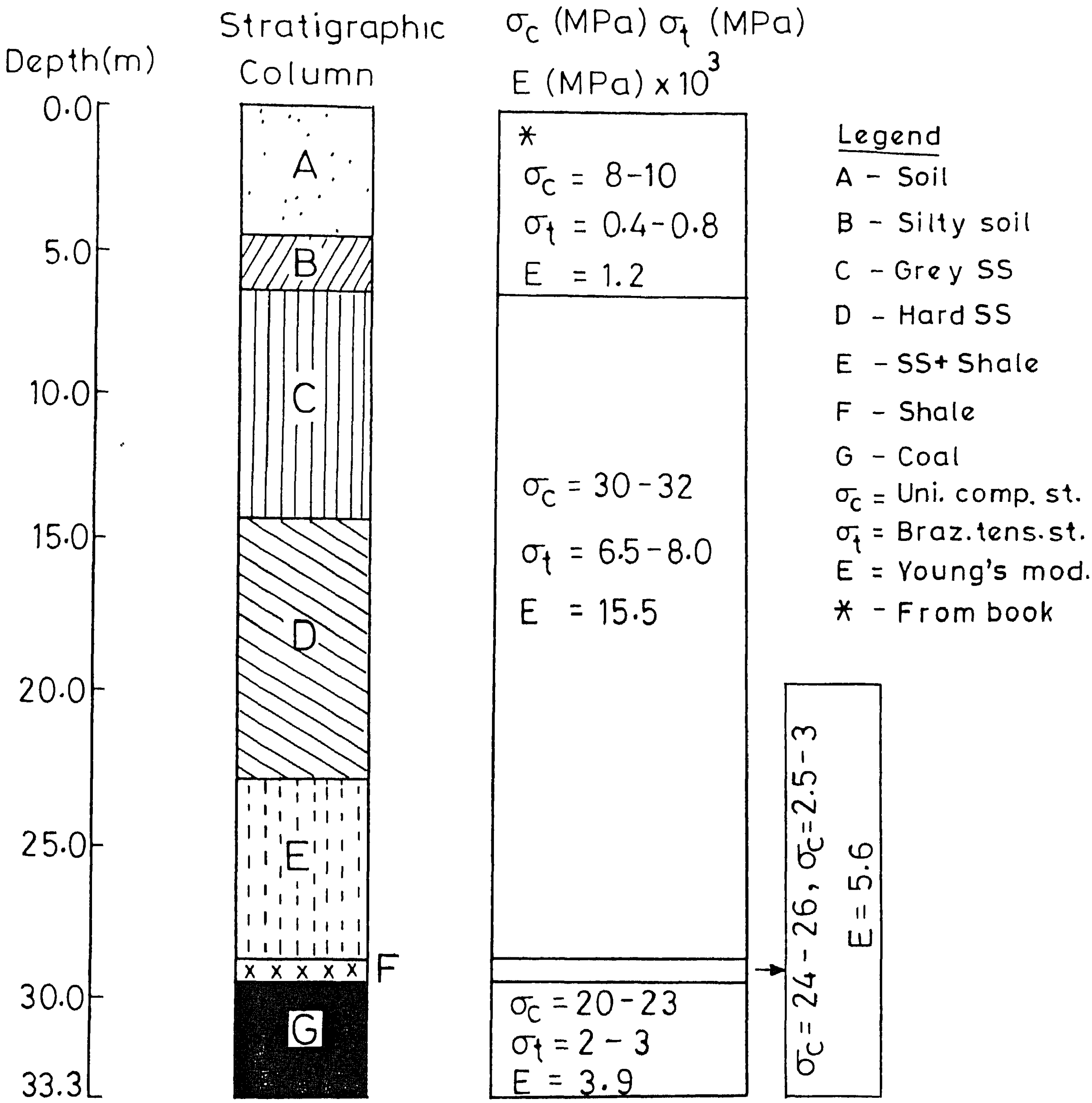


Fig. 3.8 Borehole strata in Raniganj coalfield

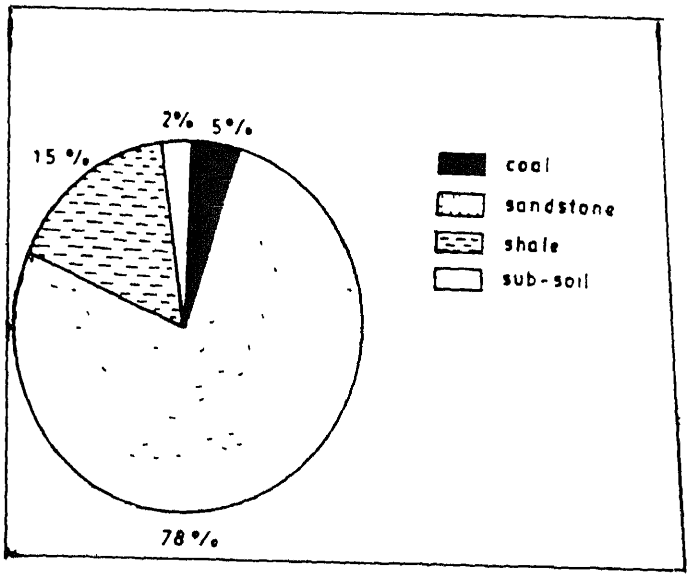


Fig. 3.9 Average composition of coal measures in Raniganj coalfield

an average width of 35 km. The total area of the coal field is 1530 square km. The strtigraphic sequence of the broad geological formations of the coal field is as given below:

Stratigraphic sequence of Raniganj coalfield

	Sequence	Thickness (m)
Panchets		
	Raniganj Measures	1040-2000
Damudas		
	Ironstone Shales	400-600
	Barakar Measures	940
Talchirs		
Archaeans		

Among these Talchirs, Ironstone shales and panchets are devoid of coal seams (CMRS, 1989).

3.5.2.1 LAND DEGRADATION:

Mining activities in RCF coal field have degraded a sizable land area and have endangered about 42 localities (township, villages and other residential areas). The land area degraded due to various reasons are (CMRS, 1991):

i).	Subsidence	43.43 Sq. km.
ii).	Fires	6 Sq. km.
iii).	External dumps	Not available
iv).	Open pits	5 Sq. km.

3.5.3 KAMPTEE COAL FIELD:

Kamptee coal field in central India with its importance to the region need special consideration from subsidence standpoint due to presence of Kampthi series of rocks and Kanhan river and its highest flood level (HFL) on the surface. Besides the water charged Kamthi and Barakar and surface water bodies the coal field also has black cotton soil. Thereforeall the extraction has been done using hydraulic sand stowing method. A maximum subsidence of 5% of extraction thickness has been observed.

The Kamptee coal field is a horse-shoe shaped reverin deposit and trends in NE - SW alignment. It extends over an area of 505 sq. km. and comprises of three sub-basins, namely, Tekadi-Silewara-Patansaongi, Saoner, and Bokhara- Dhapewada. Silewara, Kamptee and Inder collieries fall within Tekadi- Silewara-Patansaongi sub-basin of the coal field.

3.5.3.1 COAL MEASURES:

The weak Barakar formation at the collieries comprises of coal seams, shales and argillaceous sandstones. All the five coal seams (workable) are confined to Middle Barakar. The compositions of overlying rock masses are:

a.	Alluvium	20.8 %
b.	Sandstone	8.6 %
c.	Shale	33.9 %
d.	Coal	36.7 %

The top most concealing layers are sedimentary in nature such as: alluvium or detrital soil, clayey soil, sand and black cotton soil.

CHAPTER IV

PREDICTION OF MINING SUBSIDENCE

4.1. INTRODUCTION:

The extraction of coal or minerals from underground creates void which causes disturbance. As a result overlying strata collapse, resulting in subsidence on the surface. It causes damage to the man-made and natural surface features. The increasing demands of energy and mineral resources is increasing rapidly. With the increase in mining activities, mine subsidence problems may increase further. The damage due to subsidence problems can be controlled only if subsidence can be predicted.

Subsidence control measures can be taken in the following three stages:

* prediction,
* prevention, and
* protection.

The effectiveness of preventive and protective measures depend upon the accuracy of prediction of subsidence and associated parameters, e.g. horizontal displacement, slope and curvature of the subsidence trough and associated tensile and compressive strains which are needed to assess the possible damage to surface features. Once the maximum subsidence and the profile of the subsidence curve are known of a mining area, other parameters can be calculated.

4.2. MINING SUBSIDENCE PREDICTION:

Various methods have been used for the prediction of mining subsidence. Some of these methods are only applicable to particular locations. Only few methods are applicable in the prediction of mining subsidence whereas, others are purely research techniques. The prediction methods are broadly classified as follows :

4.2.1. EMPIRICAL TECHNIQUES

These methods are based on the experience gained from large number of actual field measurements, which are only applicable to the local conditions of the specific mining area. These methods offer certain advantages over functional methods and methods involving theoretical models. The latter rest on model propositions and mathematical assumptions which fit local circumstances to a greater or lesser degree, the former are derived from actual measurement.

Empirical methods are further classified as :

4.2.1.1 Graphical methods:

These methods rely on compilation and a summary of case histories in graphical form from which prediction of subsidence can be made. The best known example of graphical empirical methods is that developed by the National Coal Board (NCB) in the United Kingdom (NCB 1965, 1975). The subsidence values have been related graphically with the various parameters such as: thickness, depth, dip, panel geometry of the seam and the surface topography. The magnitude and profile of the subsidence can be predicted with the help of graphical charts. Other related parameters, such as horizontal displacements, slope,

curvature and associated horizontal strains can be calculated from the subsidence profile data. Similar techniques have been also adopted by Indian scientists who have also developed nomograms for Indian coalfields (CMRS 1991).

4.2.1.2 Profile function methods:

These methods are basically curve fitting techniques for matching the predicted profiles with measured profiles to obtain a mathematical formula for the profile curve. Further, predictions can be made on the basis of the derived formula. The following empirical equations have been suggested for subsidence profiles (Saxena et al., 1983) in Indian coalfields :

For sub-critical widths ($W < W_c$)

$$s = S_e \frac{-nx^2}{l^2 - x^2}$$

For critical width ($W = W_c$)

$$s = S_e \frac{-n\,x^4}{l^4 - x^4}$$

$$s = S(1 - x^2/l^2)^2$$

where

s= subsidence at any point at a distance x from the centre of the trough,

S = maximum subsidence (at x=0),

n = a factor governing the shape of the profile,

W = width of subsidence trough,

W_c = critical width (width corresponding to maximum subsidence).

4.2.2. METHODS EMPLOYING INFLUENCE FUNCTIONS

These methods, based on influence functions (an area of influence of a point is the area surrounding the point such that due to extraction of a small element within the area causes the subsidence at the point and the equation relating the percentage extraction of the area of influence of a point to the subsidence of that point is called as influence function) are used to describe the amount describe the amount of influence exerted by infinitesimal elements of an extraction area. The extraction of infinitesimal area dA causes infinitesimal subsidence at the surface. The elementary subsidence of point P moving radially within an elementary trough can be described as influence function $k_z(r)$, where r is the radial distance of P from dA. The function $k_z(r)$ generally has a maximum value at r = 0 and diminishes as r increases for more than one extracted element, the total subsidence at a point P is due to the sum of the influence of each element extracted (Figure 4.1). Thus, the subsidence is given by:

$$S(r) = \int k_z\,(r)\,dA$$

when polar coordinates are used, dA= r dr dθ

$$S(r) = \int_{r_1}^{r_2} \int_{\theta_1}^{\theta_2} k_z\,(r)\; r\; d\theta\; dr$$

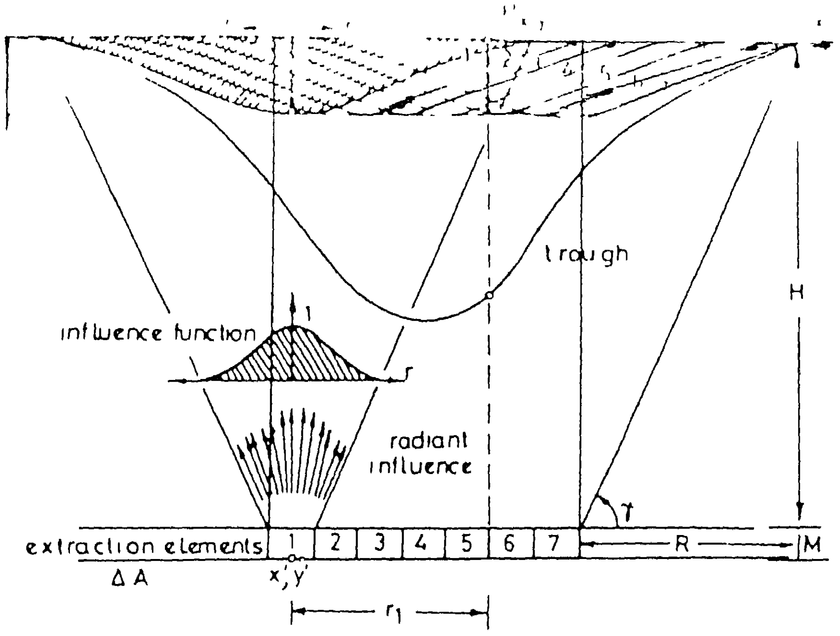


Fig. 4.1 Superimposition of elementary troughs

The value of influence function k_z can be determined from measured values of subsidence S due to an area of extraction (Kratzsch, 1983). The influence of the mined area can also be shown in a graphical form by employing an integration grid or grid zones. A critical width as diameter is drawn on tracing paper and divided into annular zones of equal subsidence. The required subsidence influence of the given extraction at a surface point on the grid is obtained by placing the center of the grid on that point and adding up the number of grid meshes and their part covering the workings (Figure 4.3).

Some of the selected influence functions are given below:

Knothe's method:

The formula derived by Knothe (1957) is based on a Gaussion distribution of probabilities:

$$k_z = [\frac{1}{R} \quad \bar{e} \ (\frac{\pi x^2}{R^2})]$$

and the equation for the normal subsidence profile (in polar form) is (Bahuguna et al., 1991) :

$$s = S \ [\ e \ (\frac{-\pi r_2}{2}) - \ e \ (\frac{-\pi r_1}{2})]$$

Keinhorst's method:

This method makes use of a formula which gives a simplified subsidence profile, the profile function is (Keinhorst, 1934) :

$$k_z = \frac{\tan^2 \beta}{3\pi(\tan^2 \beta - \tan^2 r)} \frac{S}{R^2}$$

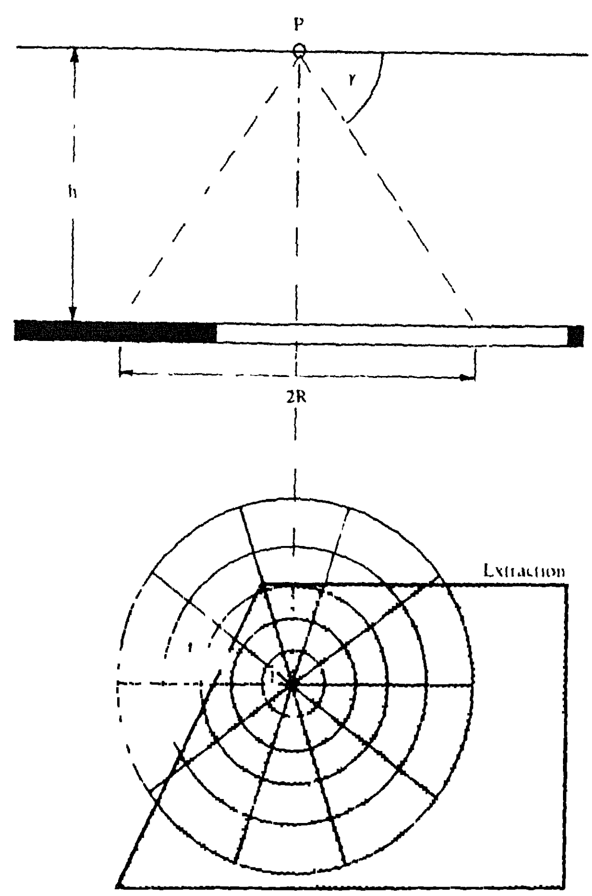


Fig. 4.2 Calculation of subsidence by the integration grid method

where:

r = angle of influence of the outer zone (angle of draw),

β = angle of break of the inner zone,

$R = h \cot r$, and

h = depth of extraction.

Bal's method:

Bal's formula is based on Newton's gravitational law, that is the influence on the surface being inversely proportional to the square of distance of the particular element. The function is expressed by (Bahuguna et al., 1991):

$$k_z = \frac{C}{R^2+h^2} \quad d\alpha$$

and in usable form:

$$k_z = \frac{C}{h^2} \quad \frac{1}{4} (\sin^2\alpha_m + 2\alpha_m)$$

where c = constant,

α_m = angle of influence measured to the vertical

Beyer's method:

This influence function for calculating subsidence is (Bahuguna et al., 1991):

$$k_z = \frac{3s}{2} [1 - (r/R)^2]^2$$

iv) other factors apart from mine geometry can be used in the form of complementary functions.

For the above reasons, influence function methods are widely used with considerable success in most of the mining areas in the world. The demerits of these methods are:

i) they become more complicated than the profile functions when an extensive area of irregular configuration is encountered,

ii) they are used to predict symmetrical subsidence profile about the trough centre which is not always the case, and

iii) The influence point in the influence function is located just above the rib side, which is not always the case.

Disadvantages (ii) and (iii) mentioned above can be overcome by modifying the influence function accordingly.

4.2.3. THEORETICAL MODELLING

Surface subsidence has been predicted using a number of theoretical models. These methods are based on statistical or mechanistic laws considering the material of the overlying strata as a model of either cohesionless stochastic or elastic or even plastic, isotropic or anisotropic medium. Based on some physical concepts, void diffusion model has also been developed and validated for longwall subsidence in Chinese coal mines (Hao and Ma, 1990) (Figure 4.4). Computer based techniques, such as the Finite Element (FEM) (Hazine 1977, Reddish 1984) Boundary Element (BEM) (Lavie and Denekamp, 1984, Mcnabbe 1987) and Distinct Element (DEM) (Coulthard and Dutton, 1984) methods of modelling of overburden rock mass and simulation of mine

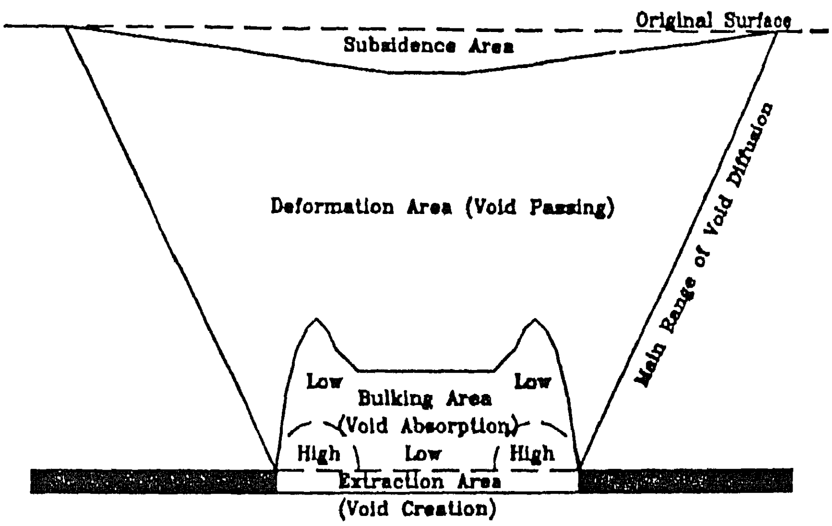


Fig. 4.4 General principles of void diffusion

geometry have been used recently for the prediction of subsidence over mine panels.

In FEM the structural analysis of the overburden and gob is made by dividing and subdividing into individual structural elements. Because of stresses in the overburden body, the nodes of the mesh experience strains and get displaced. The amount of displacement of each element depends on the level of stress and material properties of each element. In FEM the effect of regular and large numbers of geological discontinuities such as joints, faults, bedding planes, etc., and different types of rock layers in the overburden, can be taken into account as the finite element mesh is spread all over the body of the overburden. At the same time, however, this makes the method more voluminous and time consuming.

In BEM of subsidence simulation the element mesh is not spread all over the body of the overburden but only at the boundary, i.e. on the ground surface. This method is more suitable for cases where geological discontinuities are comparatively less because the method is simpler than FEM.

In DEM, the rock mass is considered as a discontinuous system of interacting blocks. This method is suitable for modelling a jointed rock mass where the deformation mechanism is mainly block separation, rotation, or slip, and there are large relative movements. This method is not yet to established in satisfactory subsidence prediction.

4.2.4. PHYSICAL MODELLING

The use of reduced scale models of the subsidence phenomenon has

been of benefit to engineers in understanding the mechanism associated with the mining excavation and the development of the subsidence trough between seam and surface. A large range of materials have been used in the past but the materials currently in use tend to be weak sand plaster mixtures. This technique is generally limited to two dimensional models. The time and effort taken in model construction again limits this prediction method to research problems rather than regular prediction. In FEM, the overburden can be taken into account as the finite element mesh is spread all over the body of the overburden.

Generally the choice of a predictive technique depends on the availability of appropriate data and the nature of problems encountered. Due to the simplicity, practical ability and possibility of the incorporation of time into the theoretical treatment of ground movement, the visco-elastic model has been used in the present work. The model is discussed in the next chapter.

CHAPTER V

PREDICTIVE MODEL FOR COAL MINE SUBSIDENCE

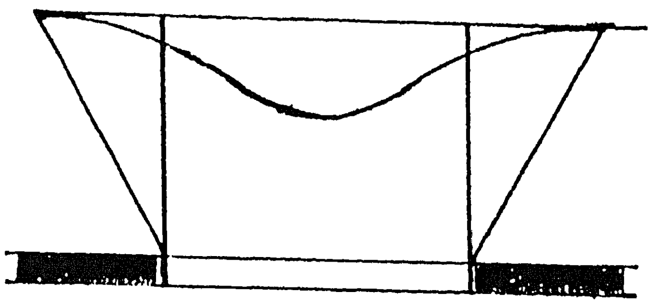
5.1 INTRODUCTION

The subsidence due to underground excavations has been observed from the earlier days of coal mining, and has attracted the attention of scientists and engineer. In the recent past, the efforts have been made to understand subsidence mechanism. Three types of subsidence profiles have been observed in Indian coal fields under different geomining conditions.

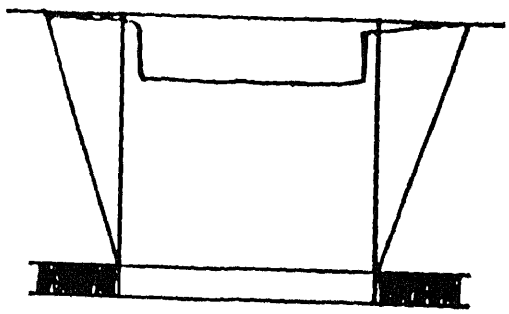
The prediction of subsidence caused by underground coal mining has been a topic of interest from long back in India. Efforts have been made in the prediction of subsidence based on empirical relations which are restricted to subsidence with continuous profiles only (Figure 5.1a). No efforts have been made for the discontinuous subsidence profile, as a result it is impossible to predict the occurrence of subsidence of discontinuous profiles (Figure 5.1b and 5.1c) (Kumar et al., 1983).

A subsidence prediction model is considered as shown in Figure 5.2, which is representative of continuous as well as discontinuous subsidence profiles. A coal mine is considered as a beam or plate, resting on a visco-elastic foundation which deforms only due to transverse shear. Various components of the coal mine model are:

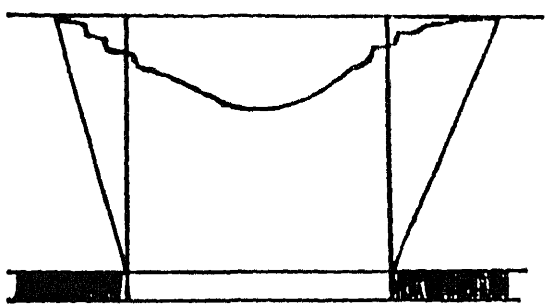
* Dash pot,



(a) Continuous subsidence profile



(b) Stepped subsidence profile



(c) Continuous subsidence profile with many small steps

Fig. 5.1 Subsidence profiles in Indian coalfields

* shear layer,
* spring, and
* overburden.

5.2 FORMULATION

The semi-infinite medium is represented by a layer of unit thickness, consisting of incompressible vertical elements which deforms due to transverse shear only. The semi-infinite medium is considered to be resting on closely spaced linear viscous elements (Figure 5.2).

The vertical equilibrium of a "shear layer" is considered as parallelopiped cut out by the vertical surfaces x, x + dx, y and y + dy as shown in Figure 5.3. The movements of the ground surface are very slow therefore, the inertia terms are neglected (Kerr, 1961). The equilibrium equation of the model is written as

$$\frac{\partial N_x}{\partial x} + \frac{\partial N_y}{\partial y} + p - q = 0 \tag{5.1}$$

Assuming in filled material as homogeneous and isotropic, therefore, according to Newton's law of viscosity

$$N_x = \mu \frac{\partial^2 w}{\partial x\, \partial t} \tag{5.2}$$

$$N_y = \mu \frac{\partial^2 w}{\partial y\, \partial t} \tag{5.3}$$

$$q = \eta \frac{\partial w}{\partial t} \tag{5.4}$$

where $\frac{\partial w}{\partial t}$ is the downward velocity of the ground surface.

Here, two constants of in filled material enter the analysis which

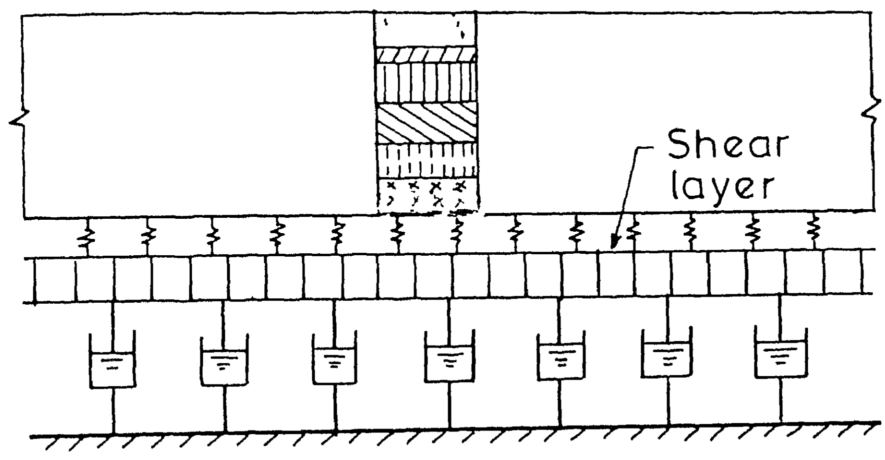


Fig. 5.2 Schematic diagram of visco-elastic model

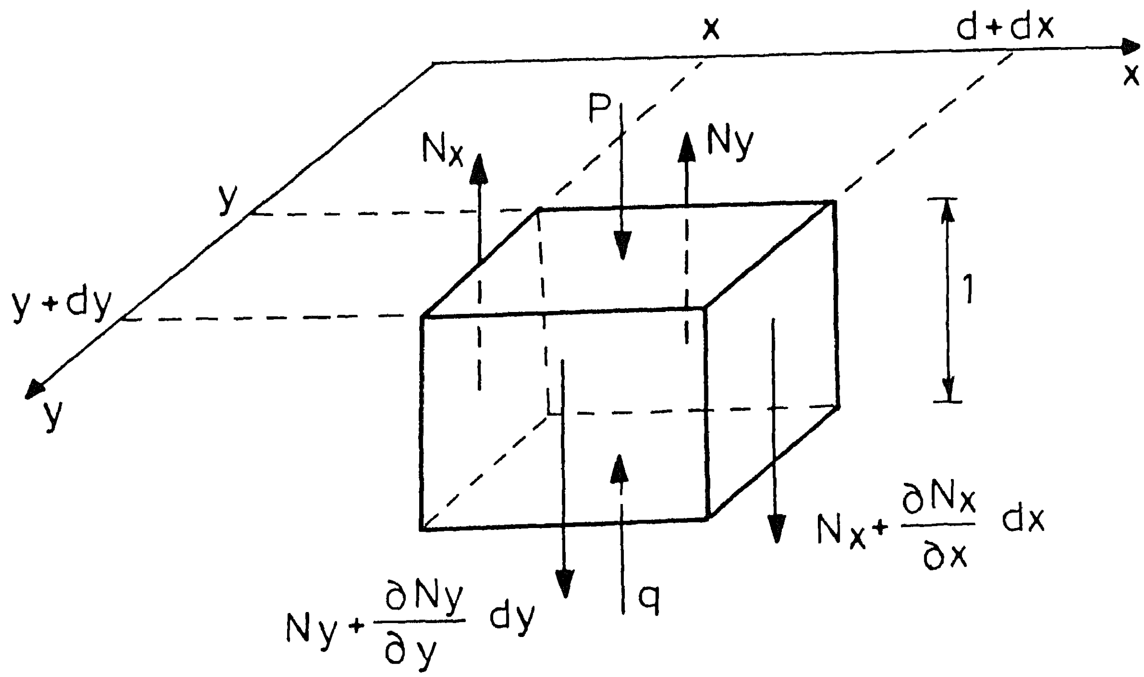


Fig. 5.3 Forces acting on a shear layer element

The overburden load (P) is uniformly distributed in the interval $-b \leq x \leq +b$. The solution for this case is obtained from the previous result setting $\bar{P}$ = pdx and integrating from -b to +b. The deflection outside the loaded region $x \geq b$ are

$$w_e = p\frac{t}{\eta} \sin h(\lambda b)\ e^{-\lambda x} \tag{5.15}$$

and the deflection inside the loaded region $-b \leq x \leq b$ are

$$w_i = P\,\frac{t}{\eta}\ [\,1-e^{-\lambda b} \cos h(\lambda x)] \tag{5.16}$$

Thus, the surface of the medium will deform according to an exponential function as shown in Figure 5.4 but the discontinuity in slope along the line of application of the "concentrated" line loads will disappear. This case simulates the subsidence phenomena with continuous profiles.

5.2.2 RIGID OVERBURDEN

In this case under the overburden, $-b < x < +b$, the subsidence w_o is constant, similar to stepped subsidence profile. The corresponding vertical pressure according to equation 5.4 is written as

$$q_o = \eta\left(\frac{\partial w_o}{\partial t}\right) \tag{5.17}$$

in which dw_o/dt is the downward velocity of the ground surface.
The subsided surface for $x \geq b$ is determined from the continuity condition that at a time t, w(x,t) will pass through $w_o(b,t)$ for any λ. Thus, according to equation 5.10, at x = b

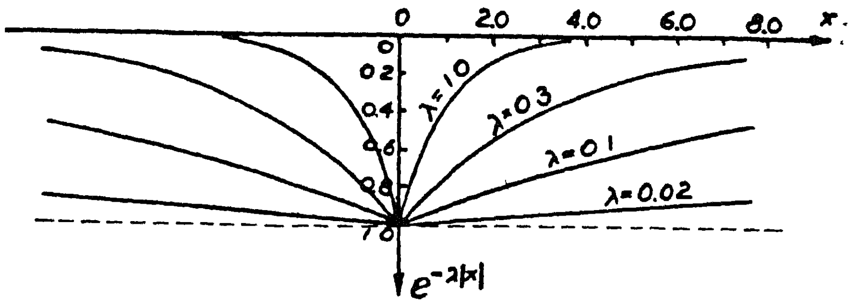


Fig. 5.4 Deflection function due to a line load $\bar{P}$ for different values of λ.

$$w_o(b,\ t) = ct\ e^{-\lambda b} \qquad (5.18)$$

It follows that $c = \frac{w_o}{t} e^{\lambda b}$. Substituting c in equation 5.10, we get

$$w_e\ (x,\ t) = w_o\ e^{-\lambda(x-b)} \qquad x \geq b \qquad (5.19)$$

and

$$q_e = \eta\left(\frac{dw_o}{dt}\right) \quad e^{-\lambda(x-b)} \qquad (5.20)$$

Substituting in the vertical equilibrium equation (per unit of length overburden)

$$\bar{P} - q_o\ 2b + 2 \int_b^\infty q_e\ dx = 0 \qquad (5.21)$$

After integrating equations 5.17 and 5.20, we get

$$\bar{P} = 2\eta\ \left(\frac{dw_o}{dt}\right) \left(b + \frac{1}{\lambda}\right) \qquad (5.22)$$

or,

$$\left(\frac{dw_o}{dt}\right) = \frac{\bar{P}}{2\eta\ (\lambda b + 1)} \qquad (5.23)$$

Equation 5.23 shows the velocity of the downward motion of the rigid overburden of width 2b. The corresponding vertical displacement is written as

$$w_o\ (t) = \frac{\lambda \bar{P}}{2\eta\ (\lambda b + 1)}\ t \qquad (5.24)$$

if it is assumed that at t = 0 the subsidence starts.

The subsidence w_o under the overburden $-b \leq x \leq +b$ is constant, no shear forces occur in this region. The pressure distribution under the strip is written as

$$q_1 = \eta\left(\frac{dw_o}{dt} \right) \tag{5.25}$$

and because of equilibrium (equation 5.22) two line loads

$$\bar{q} = \eta/\lambda \quad \left(\frac{dw_o}{dt} \right) \tag{5.26}$$

per unit length of strip act along the edges $x = \pm b$.
The overburden load (P) is uniformly distributed in the interval $-b \leq x \leq +b$, the solution is obtained from equations 5.19 and 5.24. Setting $\bar{P} = Pdx$ and integrating from $-b$ to $+b$, the subsidence outside the overburden $x \geq b$ is written as

$$w_e\ (x,\ t) = w_o\ e^{-\lambda\ (x-b)} \qquad x \geq b \tag{5.27}$$

and the subsidence inside the overburden region $-b \leq x \leq b$ is written as

$$w_o\ (t) = \lambda/\eta\ \frac{Pbt}{(\lambda b+1)} \tag{5.28}$$

The ground surface will subside , similarly the stepped subsidence profile. These results can not be used directly for the prediction of subsidence, Therefore, a computer based model has been developed incorporating these results with some necessary modification

as well as some observed facts in Indian coal fields. This computer based model is given in the Appendix A.

In developing this model, it has been considered that the model should be

* an user friendly model,
* easy to operate,
* able to provide different shapes of subsidence movement profiles which are actually observed in Indian coal fields,
* able to take care of asymmetric in subsidence movement profiles, which has actually been observed in India and abroad, and
* able to anticipate magnitude of subsidence at any time in future.

5.3 PARAMETERS OF SUBSIDENCE PREDICTIVE MODEL:

Subsidence due to underground coal mining is a very complicated phenomenon which depends upon many factors as described in Chapter II in detail. Therefore, the model uses the following parameters for the prediction of subsidence:

* overburden thickness (H),
* extraction width (W),
* extraction thickness (M),
* width/thickness ratio (W/H),
* rock mass Rating (R),
* number of layers in the overburden (N) and the following properties of each layer eg.

-layer thickness,

-structural features,

-weatherability,

-strength of the rock,

-ground water flow,

* viscosity co-efficient related to the shear deformation of in filled materials (μ), and
* vis co-compressibility co-efficient (η) of in filled materials.

5.4 DETAILS OF COMPUTER BASED MODEL

The above mentioned parameters are important in the anticipation of subsidence. The results from laboratory tests and field observations have been taken in computer modelling. The representative input values of the parameters are given in Table 5.1. In the subsidence model studies, following criterion and relationships have been considered in determining nature of subsidence profiles.

5.4.1 Determination of nature of subsidence profiles:

As described earlier, three types of subsidence profiles are considered. For a given geomining condition, the following criterion has been used to determine the subsidence profile.

RMR	w/H	Profile Type
> 60	> 2.5	Stepped
> 60	< 2.5	Smooth
< 60	-	Irregular

TABLE 5.1

Physical Parameters of Ratibati and Shivadanga Coal Mines

Parameter	Ratibati Coal Mine (m)	Shivadanga Coalmine (m)
W	122	214
H	42.5	104
M	3.8	2.4
W/H	2.87	2.06
L	189	220
RMR	*	*

*Determination of RMR and other parameters related to it are based upon Figure 3.8 and Table 5.2

The rock mass rating (RMR) is based upon the CMRS geomechanies classification system. This system , widely used in India, is a simple and practical method of estimating roof conditions in a mine. The rating system used by this system is shown in Table 5.2. This system has been developed by Venkateshwarlu (1986) of the Central Mining Research Station (CMRS) of India after modifying the geomechanics classification given by Bieniawski (1979) for estimating roof conditions and support in Indian coal mines.

5.4.2 <u>Effective Time Determination</u>:

Time subsidence relationship obtained from results discussed in Section 5.2 is linear which does not match from the observation. Therefore, the computer based model uses effective time in the said results, which is determined as follows:

$$T_{ei} = T_{e(i-1)} + 1/T_i^4 \qquad T_{i>1}$$

$$T_{e1} = 1 \qquad T_i = 1$$

where, T_{ei} is effective time corresponding to the real time T_i in year.

5.4.3 <u>Determination of constants λ and μ by Back Analysis Techniques</u>:

The procedures leading to the determination of the values of unknown (or barely defined) parameters by the method of successive approximations are commonly referred to as back analysis technique. In general terms, a back analysis problem is solved by defining the values of the unknown quantities (e.g. material properties) in a mathematical model, the use of which leads to results (e.g. displacements) as close as possible to the corresponding in-situ

hence, results obtained in section 5.3.1 is used.

c) Irregular Profile:

In this case results of section 5.3.1 has been used, here, though it is not possible to predict the subsidence magnitude accurately.

5.4.5 Determination of shift of maximum subsidence point (θ) from vertical and dip (both are in degree):

Shift (θ) and dip (D) are related as:

$$\theta = \exp (D1)$$

where,

$$D1 = \log 10 \,(w/H + D - 0.6)$$

CHAPTER VI

RESULTS AND DISCUSSION

6.1 INTRODUCTION

The subsidence in coal mine areas is very common due to which loss of life and property is taking place. In order to avoid the loss of life and property, the prediction of subsidence in such areas is important. It is also required to predict subsidence due to any future extraction of coal in such areas.

In the present work, we have carried out detailed numerical studies to predict subsidence due to underground coal mining in general and in particular to the coal mining in Raniganj coal field. We have used a visco-elastic model to compute subsidence and have studied the effect of various parameters influencing subsidence. We have also developed relationships among the intrinsic parameters of the model. We have compared the predicted and observed subsidence for Ratibati and Shivdanga coal mines of Raniganj coal field. The results show very good similarity in the predicted and observed subsidence of Raniganj coal field areas.

Results and discussion

We have taken various coal mine models representative of coal mines of Raniganj coal field and have carried out detailed numerical studies to predict the subsidence. Figure 6.1 shows the computed

subsidence up to 200 m from the center of the Ratibati coal mine on the surface. The maximum subsidence observed at the centre of the mine is about 1 m. The effect of subsidence is seen up to about 150 m on both the sides from the centre of the coal mine, beyond 150 m the subsidence is not very appreciable. The predicted subsidence profile is quite similar to the observed subsidence profile in the coal mine. The predicted subsidence is shown by the solid line whereas, the observed subsidence is shown by star (*) symbols (Fig.6.1).

The computed subsidence in the case of Shivadanga coal mine is shown in Figure 6.2. The computed subsidence shows its effect upto 400 m on the either side of the coal mine. Maximum subsidence is found to be of the order of about 1.5 m at the centre of the mine, which is quite similar to the observed subsidence. The effect of the observed subsidence is seen upto only 100 m on the either side of the mine. The difference in the predicted and observed subsidence on the either side of the mine can be attributed to the difference in the parameters taken for modelling and with the real parameters.

6.2 Subsidence Profiles

The prediction of subsidence profile has been done for both Ratibati and Shivadanga coal mines of Raniganj coalfield. The predicted subsidence profiles has been found to be stepped and smooth for Ratibati and Shivadanga coal mines, respectively. The observed subsidence profiles in these mines are similar in nature to those of predicted with some variations. In the case of rigid overburden (in the case of Ratibati coal mine) computed and observed profiles are

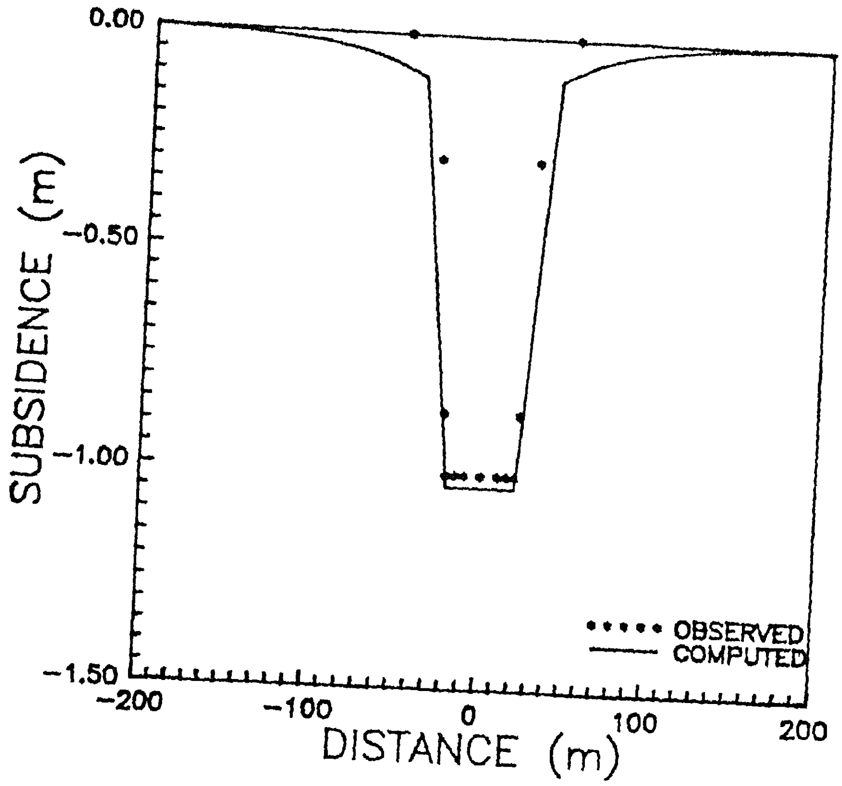


Fig. 6.1 Subsidence profile in Ratibati coal mine

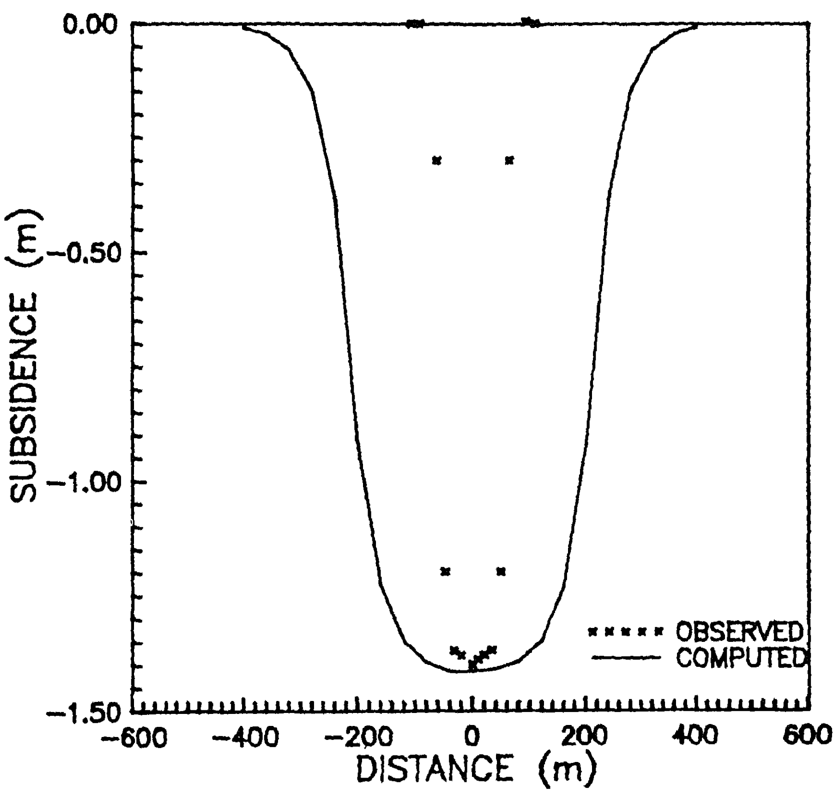


Fig. 6.2 Subsidence profile in Shivadanga coal mine

quite matching (Figure 6.1). In the next case, where overburden is flexible in the case of Shivadanga) computed and observed profiles are reasonably deviated to each other and the match is not satisfactory (Figure 6.2). Figures 6.3 and 6.4 show the three-dimensional view of subsided area in Ratibati and Shivadanga coalfields, respectively.

6.3 Effect of Time on Subsidence

The strength of the rock or earth's material changes with time, therefore, the subsidence in the coal mine is also time dependent phenomena. Figure 6.5 shows the effect of time on subsidence for the three cases of excavation widths of 120 m, 240 m and 720 m, respectively. It has been found that subsidence increases continuously upto first two years, after excavation. The subsidence attains a maximum value which remains almost constant with the increase in time, which shows that the subsidence changes only at the initial period of two years and afterwards it becomes stabilized. This is according to the geomining conditions, which does not change with time. This behaviour is similar with the increase of the width of the excavation, however, the subsidence increases with the increase of the width of excavation (Figure 6.5).

6.4 Effect of Overburden Thickness on Subsidence and Subsidence Factor

Figures 6.6 and 6.7 show the effect of overburden thickness on subsidence and subsidence factors respectively. In each of the four cases, overburden thickness varies within a wide range while keeping excavation widths of 400 m, 600 m, 800 m and 1000 m, respectively. The

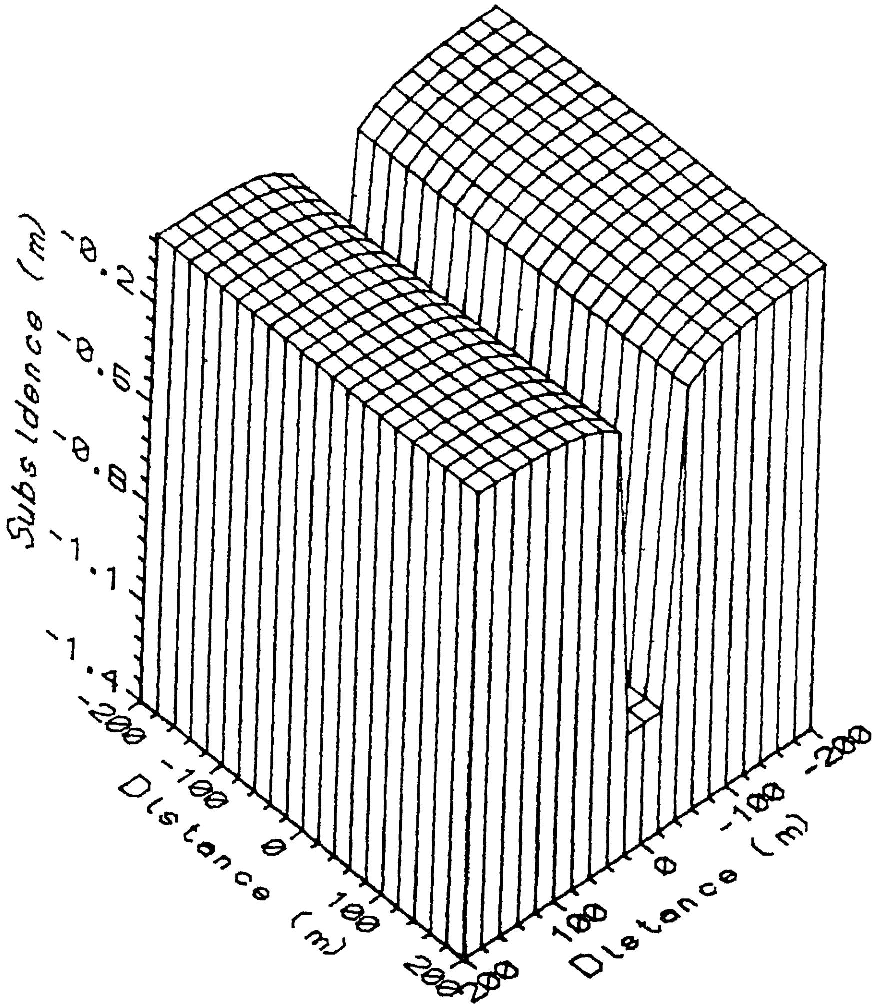


Fig. 6.3 Three-dimensional view of subsided area in Ratibati coal mine

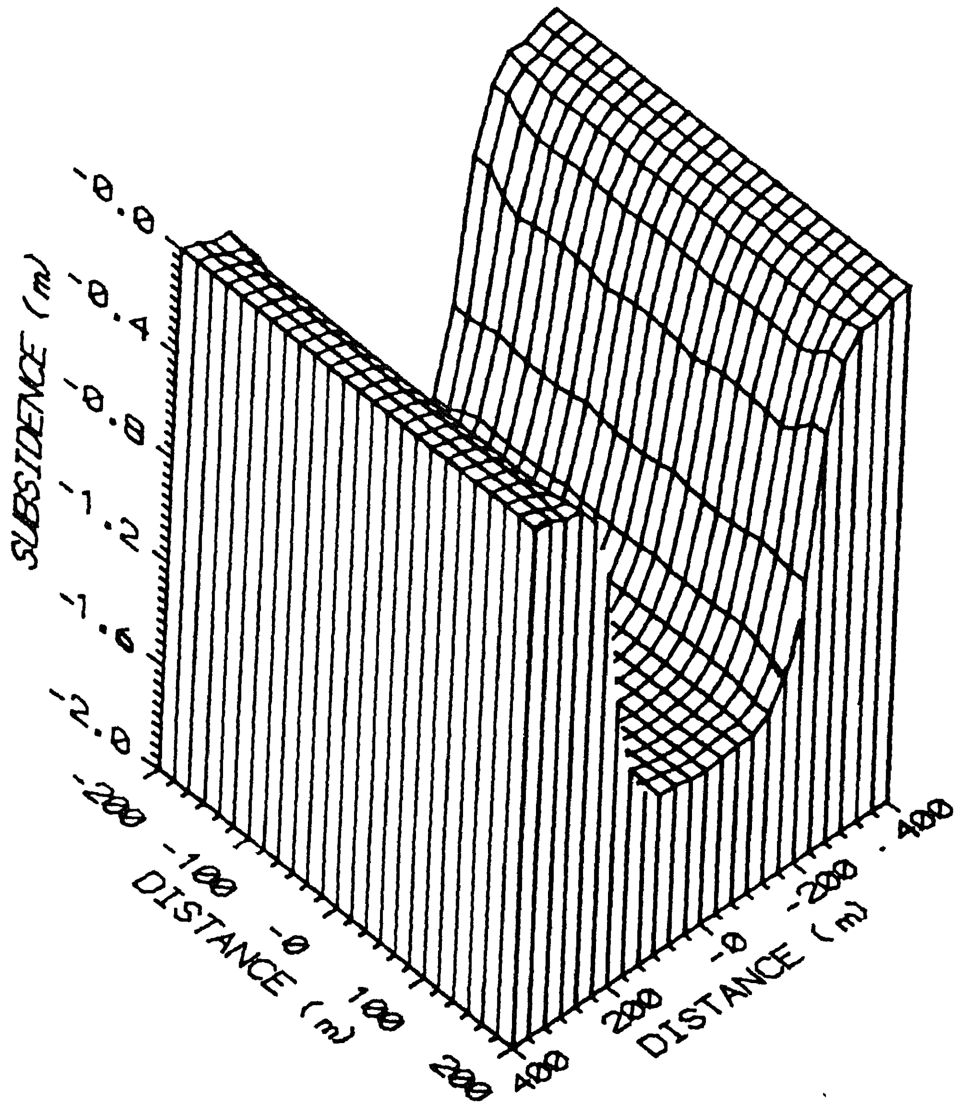


Fig. 6.4 Three-dimensional view of subsided area in Shivadanga coal mine

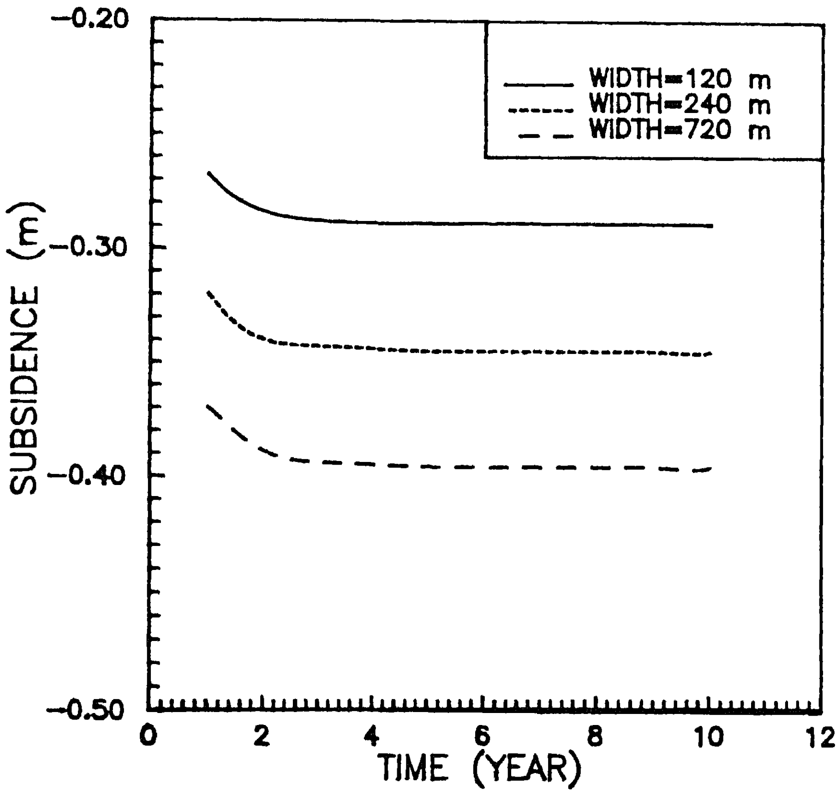


Fig. 6.5 Variation of subsidence with time

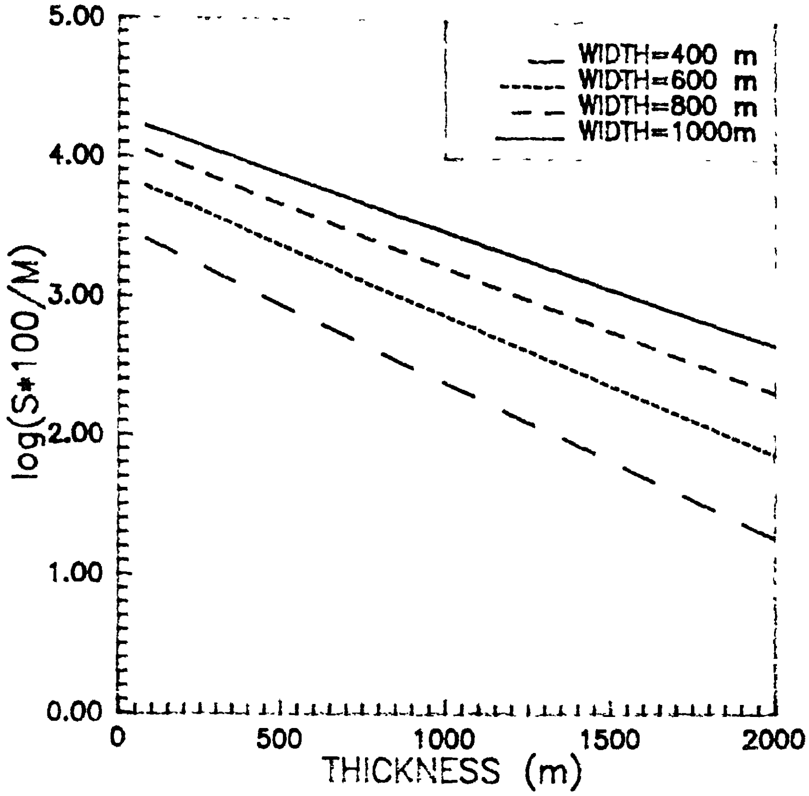


Fig. 6.8 Variation of logarithmic value of subsidence factor expressed in percentage with overburden thickness

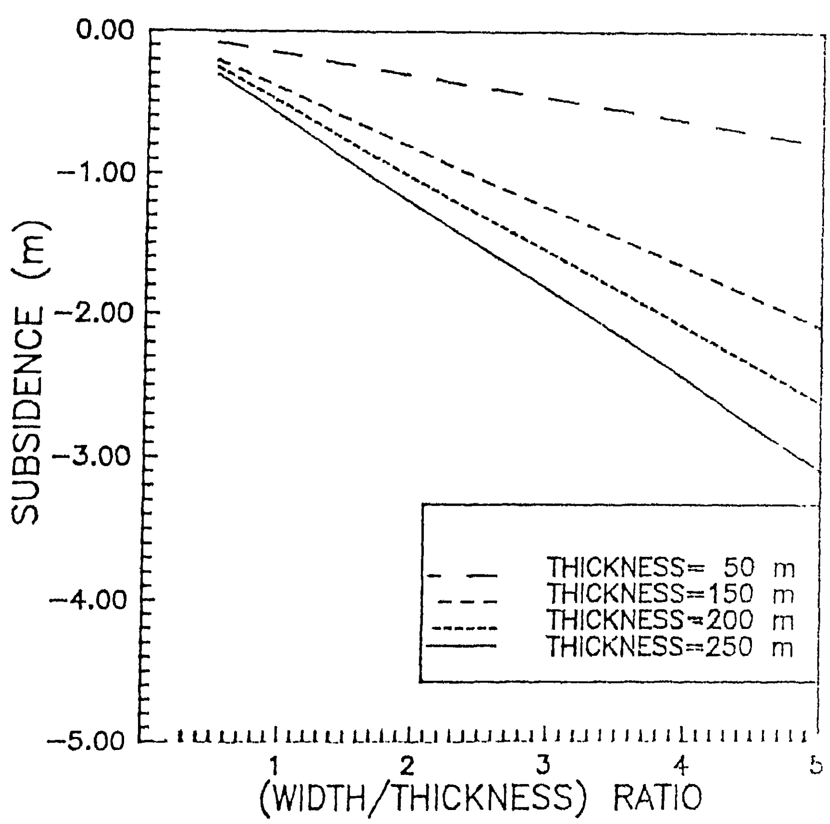


Fig. 6'9 Variation of subsidence with width to overburden thickness ratio

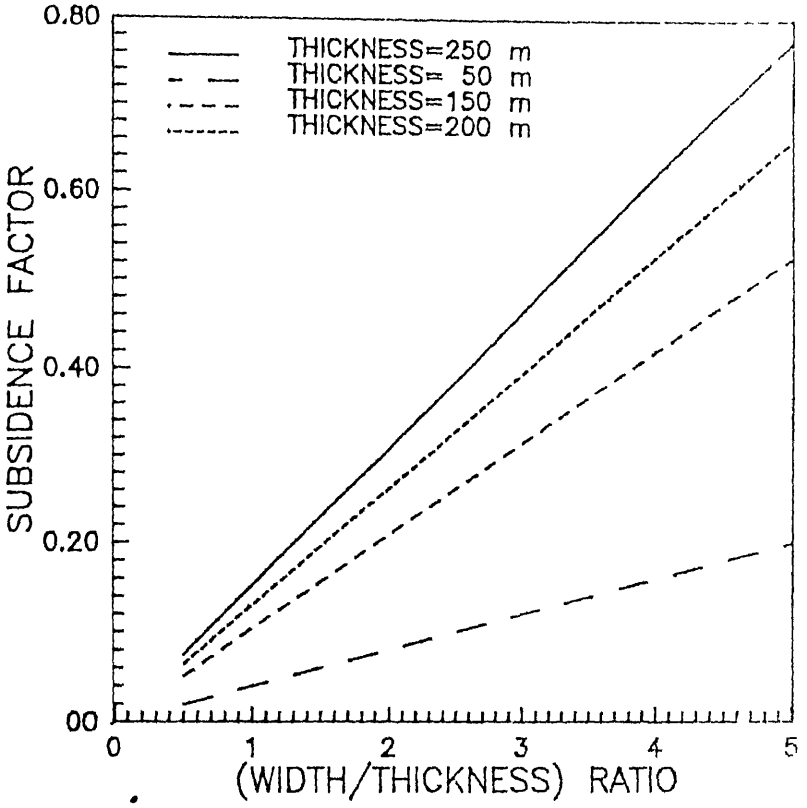


Fig. 6.10 Variation of subsidence factor with width to overburden thickness ratio

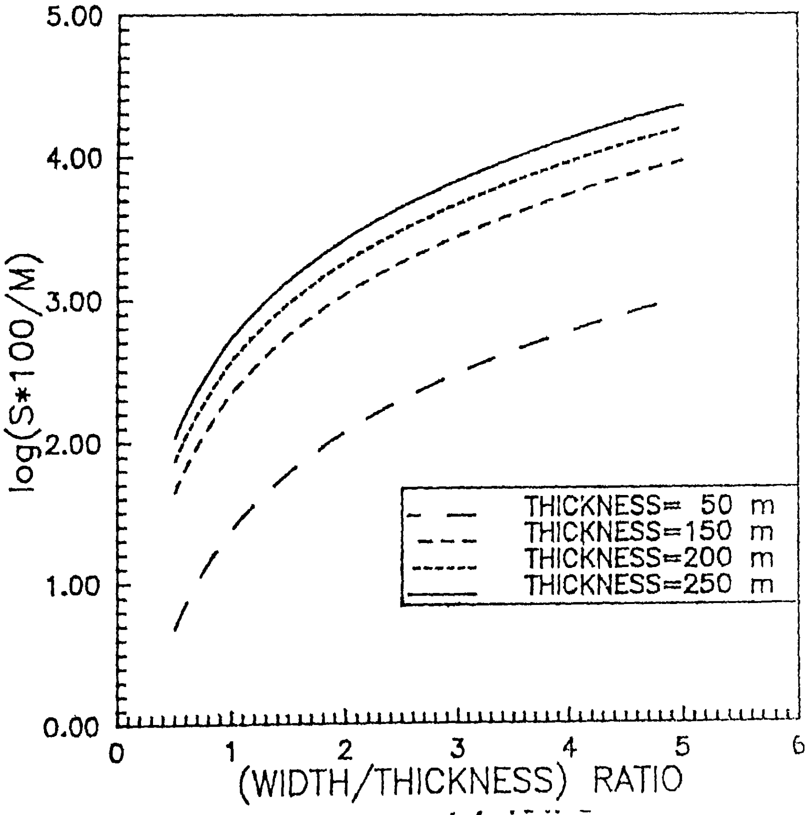


Fig. 6.11 Variation of logarithmic value of subsidence factor (percentage) with width to thickness ratio

variation of logarithmic value of subsidence factor expressed in percentage has been found to be non-linear.

6.7 Inter Relationship among Intrinsic Parameter Values

All the three intrinsic parameters (λ, μ, η) play very important role in subsidence prediction, because these are constants of infilled material indirectly related to the method of mining, efficiency of stowing etc. All the three intrinsic parameters are related to each other. μ increases linearly with λ but η increases rapidly as shown in Figures 6.12 and 6.13, respectively. η with increase in μ increases more rapidly as shown in Figure 6.14. These relationships are found to follow the following equations :

$$\mu = 95.145\,\lambda - 0.4$$

$$\eta = 11825.7\,(\lambda)^{3.127}$$

$$\eta = 0.226 - 0.001\,\mu + 5.62 \times 10^{-7}\,(\mu)^2 + 9.94 \times 10^{-9}\,(\mu)^3$$

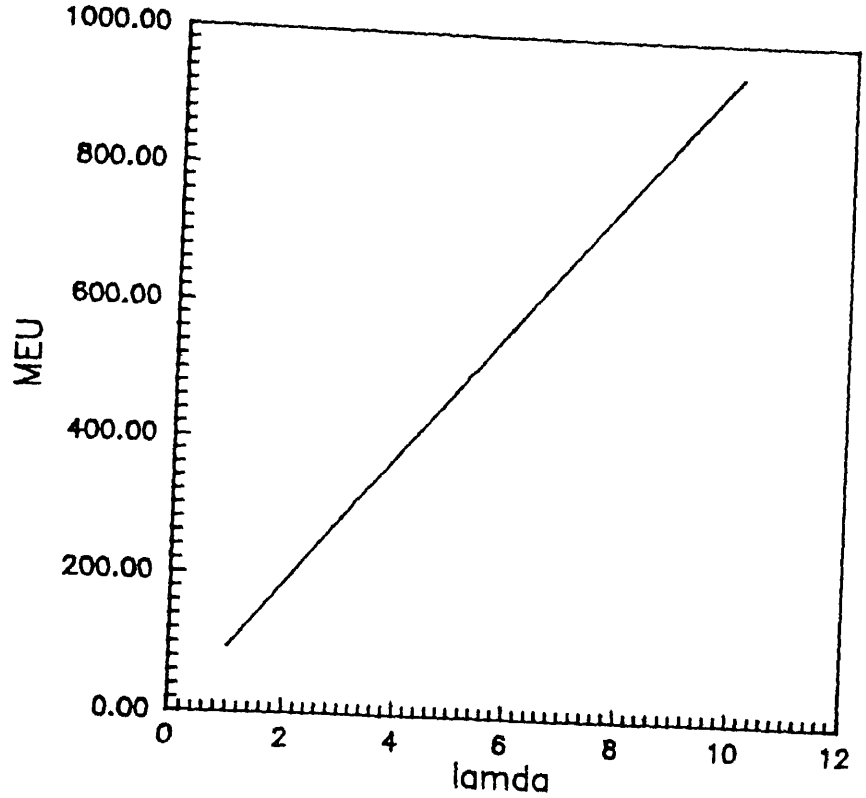


Fig. 6.12 Variation of μ with λ

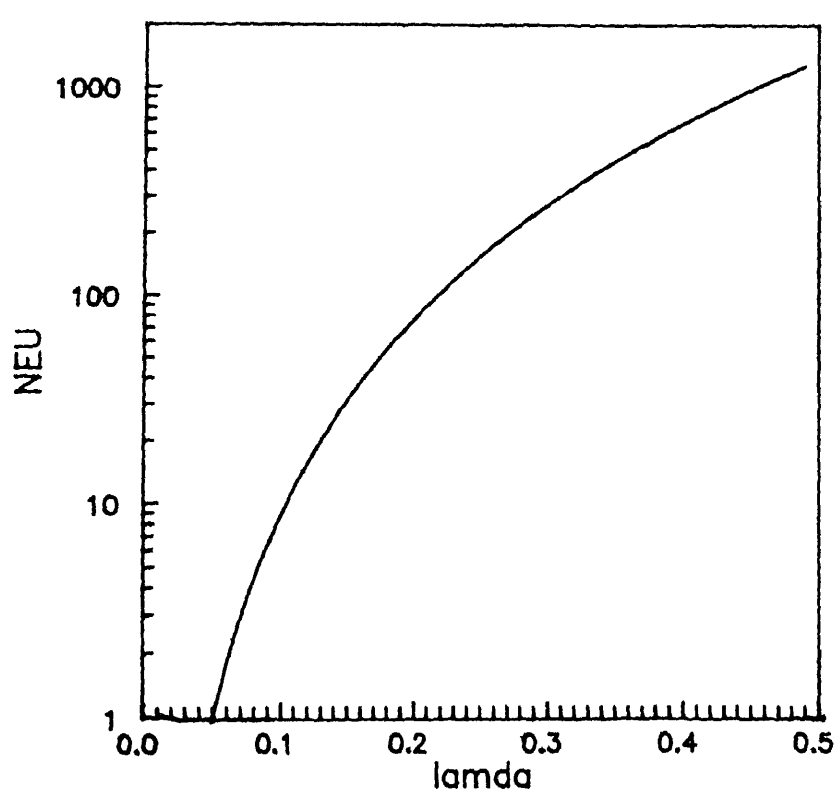


Fig. 6.13 Variation of η with λ

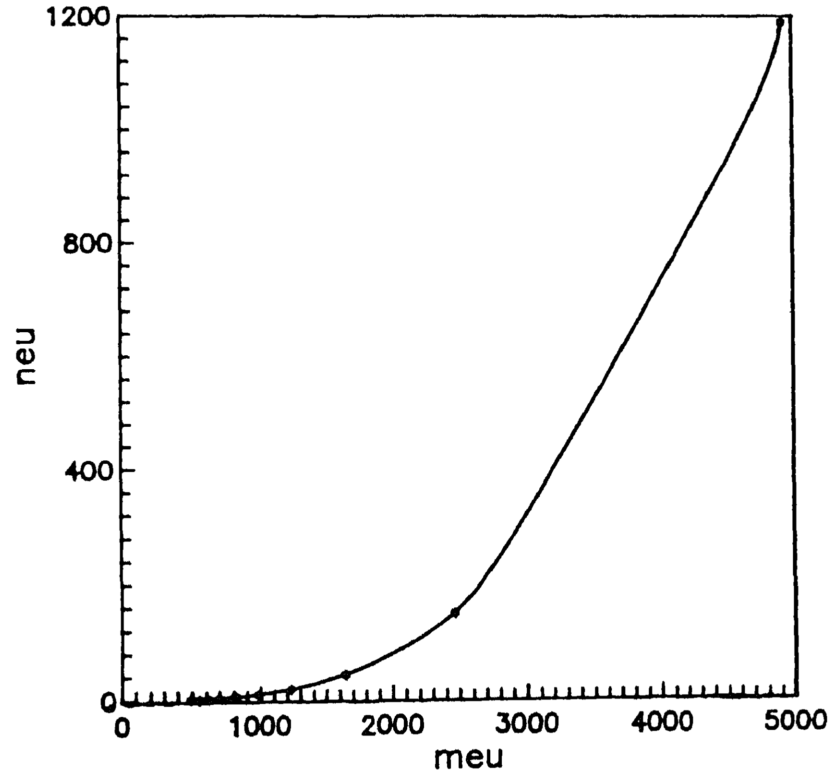


Fig. 6.14 Variation of η with μ

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The present study has been carried out to predict the subsidence profiles due to underground coal mining in Indian coalfields and to investigate the effect of various factors on subsidence and subsidence factors. Inter relationship among intrinsic model parameters has also been studied. For the validation of the proposed visco-elastic model for Indian coal mines, the subsidence phenomenon in two coal mines named Ratibati and Shivadanga of Raniganj coalfield has been investigated.

In both of the mines under consideration, the nature of predicted subsidence profile has been found quite similar to that observed in the field. The maximum computed subsidence has also been found in good agreement with the observed data in both the coal areas. In the case of Shivadanga coalfield, subsidence nature, is similar, however, the predicted subsidence profile is spread over a larger area compared to those of observed. This may be because of site factors which is not considered exactly in the theoretical model. The shape of the subsidence profile with the magnitude of maximum subsidence could be very useful in locating the zone of influence, zone of maximum damages and control and planning of mining subsidence. Further, the knowledge

of the variation of subsidence with time could be used in the subsidence prediction for future.

The effect of time on subsidence is quite significant. Subsidence is found to increase up to about two years after excavation and after two years it becomes constant. The time taken to attain the maximum subsidence is also found to increase with width of excavation.

The width of excavation and thickness of overburden are very important physical dimensions from the subsidence point of view. Both the subsidence and subsidence factor are found to increase and decrease with the increase of the width of excavation and thickness of overburden, respectively.

Subsidence and subsidence factor increase linearly with the increase of width of excavation to overburden thickness ratio. Therefore, in pre-planning of mines from subsidence control point of view, the maximum width of extraction, minimum thickness of overburden and the maximum value of extraction width to overburden thickness ratio should be fixed.

7.2 Recommendation for further work:

In order to ensure the effective subsidence control, reliable subsidence prediction techniques and good understanding of the mechanism of subsidence are important. The subsidence prediction techniques should be developed considering non-homogeneity, anisotropy and existing geological structures. It will require detailed site studies and regular monitoring of subsidence. Therefore, competent research group should be assigned in subsidence monitoring and data analysis To understand mechanism of subsidence physical modelling and image techniques should also be applied.

An expert system should be developed incorporating a set of identified factors and safe limits of settlements for different civil engineering structures for assessment of damages caused by mining subsidence. It will be helpful in fixing maximum extraction width, minimum overburden thickness etc. to avoid damage in a given geomining conditions. In an area where subsidence is anticipated, structures which are less sensitive towards subsidence should be preferred. Subsidence should be one of the main points of consideration in pre-planning and mine management.

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APPENDIX

APPENDIX

```
C ..............................................................
C     COMPUTER PROGRAM FOR SUBSIDENCE PREDICTION  USING  VISCO_ELASTIC
C                        MODEL  FOR INDIAN COALFIELDS
                     PROGRAM WRITTEN BY Ram Naresh Yadav
C. ...........................  .......................... .  ...
      DIMENSION T(80),G(80),W(80),D(80),RMR(80),
       1      A(80),B(80),C(80),ST(80),TR(80),S(80),
       2      WZ(80),W1(80,80),W11(80,80),WW1(80,80),
       3      WX(80,80),WX1(80,80),D12(80),S1(80),
       4      D1X(80)
      COMMON/BLOCK1/P,DB,D1,I1,AMT,PWD,AMT1
      OPEN(UNIT=1,FILE='R1.D')
      OPEN(UNIT=2,FILE='S2.F')
      WRITE(*,*)"ENTER :NO OF LAYER,SPAN,SEAM THICKNESS,DEPTH"
69    READ(*,*)N,DB,SH,DH
      WRITE(*,*)"ENTER 1 OR 2 FOR CAVING OR STOWING RESPECTIVELY"
      READ(*,*)METHOD
      WRITE(*,*) "ENTER PILLAR WIDTH "
      READ (*,*)PWD
      IF (METHOD-1)6,7,6
6     AMT1=6
      AMT2=.6
      GO TO 8
7     AMT=1
      AMT1=5
      AMT2=.5
8     AA=1
      WRITE(2,*)"            OVERBURDEN PROPERTIES"
      WRITE(2,*) "          ........... ..................."
      WRITE(2,*)"NUMBER OF LAYERS· ",N
      WRITE(2,*)"SPAN   OF ENTRY : ",DB
      DO 130 I=1,N
      READ(1,*)TR(I),T(I),S(I),W(I),ST(I),G(I),D(I)
  130      CONTINUE
      DO 100 I=1,N
```

```
      WRITE(2,*)"            LAYER NUMBER ",I
      WRITE(2,*)"       ........................ "
      RMR(I)=TR(I)+S(I)+W(I)+ST(I)+G(I)
      WRITE(2,*)"ROCK MASS RATING=",RMR(I)
      WRITE(2,*)"UNIT WEIGHT     =",D(I)
      WRITE(2,*)"THICKNESS       =",T(I)
100         CONTINUE
             A(1)=0 0
      B(1)=0.0
      C(1)=0.0
      NN=N+1
      DO 120 I=2,NN
      A(I)=A(I-1)+D(I)*T(I)
      B(I)=B(I-1)+RMR(I)*T(I)
      C(I)=C(I-1)+T(I)
120         CONTINUE
      AA=A(N)
      BB=B(N)
      RR=C(N)
      RM=BB/RR
      DN=AA/RR
      WRITE(2,*)"           AVERAGE PROPERTIES OF OVERDEN"
      WRITE(2,*)"      ........................................ "
      WRITE(2,*)"ROCK MAss RATING=",RM
      WRITE(2,*)"UNIT WEIGHT=",DN
      WRITE(2,*)"TOTAL THICKNESS=",C(N)
      TD=C(N)
      DP=DN*DB
      P=DN*TD
      DO 200 K=1,5
      IF(RM-(K*20))90,90,200
90 GO To(70,70,5,5,5)K
200 CONTINUE
      DP=DN*DB
      P=DN*TD
 '0 WRITE(2,*)" SUBSIDENCE PROFILE:SMOOTH WITH MANY SMALL STEPS'
```

```
      WRITE(2,*)".............................................."
      GO TO 450
    5 WRITE(*,*)"ENTER DB/DT"
      READ(*,*)D1
      IF(D1-2.50)60,50,50
   60WRITE(2,*)"          SUBSIDENCE PROFILE   :    SMOOTH"
      WRITE(2,*)"          ......................................"
      GO TO 450
   50WRITE(2,*)"          SUBSIDENCE PRFILE    :     STEPPED"
      WRITE(2,*)"          ........................................"
      GO TO 400
  400 WRITE(*,*)"ENTER THE NUMBER ACCORDINGLY YOUR REQUIREMENT"
      WRITE(*,*)      " REQUIRED CURVE DATA   INPUT NUMBER"
      WRITE(*,*)       "    DISTANCE VS SUBSIDENCE     1"
      WRITE(*,*)       "    DB/DT     VS  SUBSIDENCE    2"
      WRITE(*,*)       "    TIME      VS  SUBSIDENCE    3"
      WRITE(*,*)       "     DIP      VS  SHIFT         4"
      READ(*,*)AN
      GO TO(401,402,403,404)AN
  401 DO I1=10,-10,-1
      IY=I1*20
      DO 600 XX=10,-10,-1
      AX=XX*20
      CALL RIGID(AX,5.0,WK,AM,MEU,NEU)
      WRITE(2,111)AX,IY,WK
  600 CONTINUE
      END DO
      GO TO 11
  402 WRITE(*,*)"ENTER WIDTH & DEPTH "
      READ (*,*)WD,DP
      DO I2=1,5
      DB=WD*I2
      WRITE(2,*)"WIDTH=",DB
      DO I1=5,10
      D13=I1*0.5
      D1=D13
```

```
      DH1=DB/D1
      CALL RIGID(0,5.0,WK,AM,MEU,NEU)
      WK1=-WK/SH
      WK2=WK1*100
      WK3=LOG(WK2)
      WRITE(2,113)DH1,D1,WK,WK1,WK3,AM,MEU,NEU
113   FORMAT (8F10.3)
      END DO
      END Do
      DO I2=1,5
      DH=DP*I2
      WRITE(2,*)"OVERBURDEN THICKNESS=",DH
      DO I1=5,10
      D13=I1*0.5
      D1=D13
      DB=DH*D1
      CALL RIGID(0,5.0,WK,AM,MEU,NEU)
      WK1=-WK/SH
      WK2=WK1*100
      WK3=LOG(WK2)
      WRITE(2,113)DB,D1,WK,WK1,WK3
      END DO
      END DO
      GO TO 11
403   WRITE(*,*)"ENTER DB/DT "
      READ (*,*)D1
      DO I1=1,10
      DB=DB*I1
      WRITE(2,*) " WIDTH=",DB
      S1(1)=0.0
      DO 603 TM=2,21
      TM1= TM-1
      S1(TM)=S1(TM1)+1/(TM1**4)
      T1=S1(TM)
      CALL RIGID (0,T1,WK,AM,MEU,NEU)
      WRITE(2,111)TM1,WK
```

```
603   CONTINUE
      END DO
      GO TO 11
404   WRITE(*,*)" ENTER DB/DT"
      READ(*,*)D1
      DO I1=1,10
      DO 604 TH=1,10
      TH1=TH*2
      DIP=TH1
      Y1=D1+DIP-0.6
      SD1=ALOG(Y1)
      SD=EXP(SD1)
      WRITE(2,111)DIP,SD
604   CONTINUE
      END Do
      GO TO 11
11    AAA=1
111   FORMAT (3X,6F10.3)
      STOP
      END
      SUBROUTINE RIGID(AX,T1,WK,AM,MEU,NEU)
      COMMON/BLOCK1/P,DB,D1,I1,AMT,PWD,AMT1
      DIMENSION WX1(80,80),W1(80,80),WW1(80,80)
      X=AX
      D10=D1
      D3=0.2458/(D10*0.7)
      AM1=D3*AMT
      K=I1
      AM=(AM1)/5
      Y=10.0
      CC1=Y*0.00001
      MEU=AM/CC1
      NEU=(AM**2)*MEU
      CC2=P*T1*DB
      CC3=AM*DB
      CC4=CC3+1
```

```
333  WX(X1,T11)=WX(-X1,T11)
     GO TO 504
222  C3=AM*X1
     C4=AM*DB
     C5=SINH(C4)
     C6=EXP(-C3)
     C7=COSH(C3)
     C8=EXP(-C4)
     DB9=DB/2-PWD
     IF(X1-DB)490,490,500
490  WX(X1,T11)=C2*(1-(C7*C8))
     GO TO 504
500  WX(X1,T11)=C2*C5*C6*AMT2
504  IF(0.001-WX(X1,T11))510,510,505
505  WX(X,T11)=0.0
510  XK=-WX(X1,T11)
     WRITE(*,*)P,AM,MEU,XK,AMT
     RETURN
     END
```

CHAPTER III

COAL MINING AND SUBSIDENCE IN INDIA

3.1 INTRODUCTION

Coal mining in India has a history of over 200 years. The coal mining started at Raniganj in West Bengal in 1774. Coal, besides being a prime source of energy, is also a raw material. It is an indispensable input in steel and chemical industries. About 60 percent of the country's commercial power requirements is fulfilled by coal. The coal production in India has rapidly increased in last four decades. Coal has been the basis of industrial revolution. It is the major primary source of energy and contributes maximum to industries as fuel.

3.2 RESERVES AND PRODUCTION

The geological survey of India (GSI), according to its surveys till January 1989, have put the country's proven coal reserves at 17,633.04 crore tonnes. Figure 3.1 shows the spatial pattern of the coal reserves in India up to January 1989. The largest reserve of coal is found in Bihar State which accounts for about 33.53 percent of the total coal reserve in India, and the second largest coal producing state is Orissa accounting for 23.57 percent. Out of total coal reserves in India, 90.3 percent of coal is found in the states of Bihar, Orissa, West Bengal and Madhya Pradesh (Qureshi, 1989).

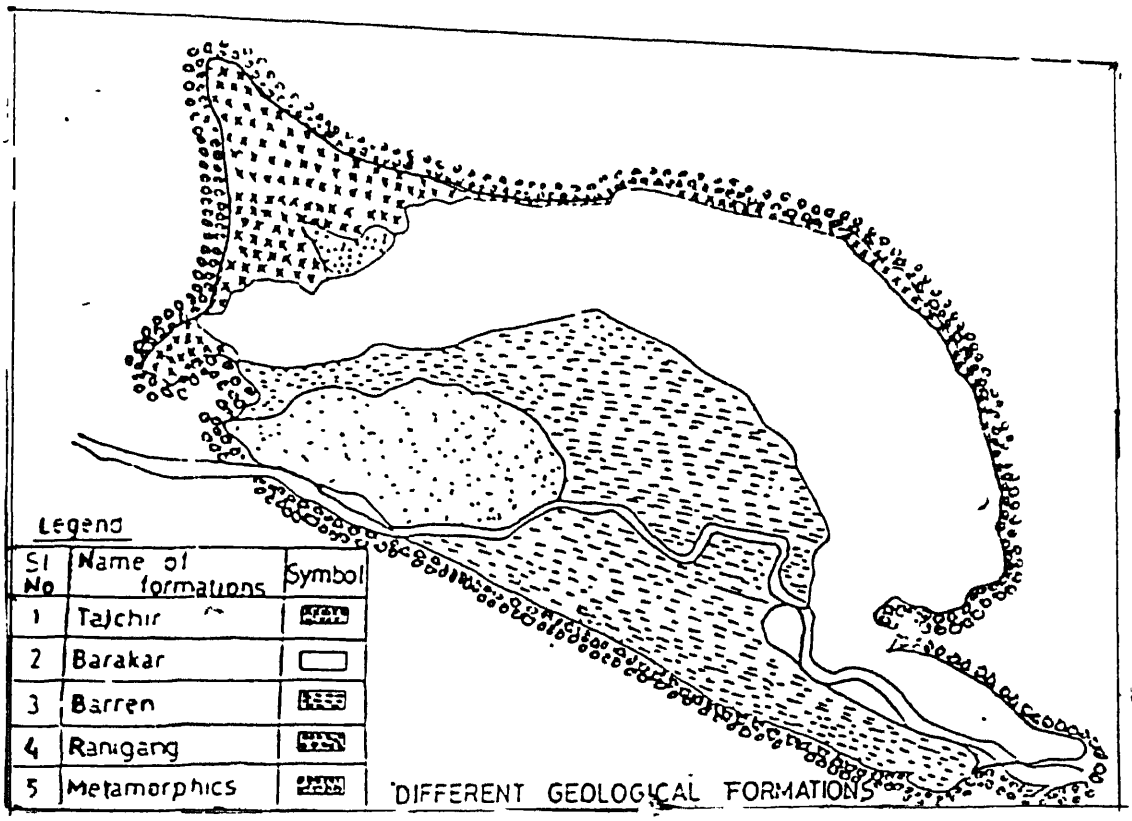

Fig. 3.5 Geological map of Jharia coalfield

26.6, respectively.

3.5.3.4 SUBSIDENCE:

A vertical movement of 36 - 71 mm has occurred due to the effect of climatic variation on the black cotton soil over Long wall panel at Silwara colliery, while no such prominent effect was observed at Kamptee and Inder collieries. This could be due to disturbances already caused by earlier mining activities and also due to large magnitude of subsidence movements at these collieries.

The maximum subsidence observed over the Long wall panels at Silewara and Kamptee collieries are 104 and 305 mm, which are 2.6 and 8.5% of the extraction thickness of 4 and 3.6 m, respectively. This higher percentage of subsidence at Kamptee is due to settlement of overlying stowed goaves in addition to settlement in current workings.

It is obvious from the above descriptions that mining subsidence is very intimately connected with the underground mining processes in India. Therefore, the safety measures are required well in advance and during the mining operations for the safety of structures and other features existing on the surface along with the safety of underground for effective exploitation of underlying coal (Prasad et al., 1989).

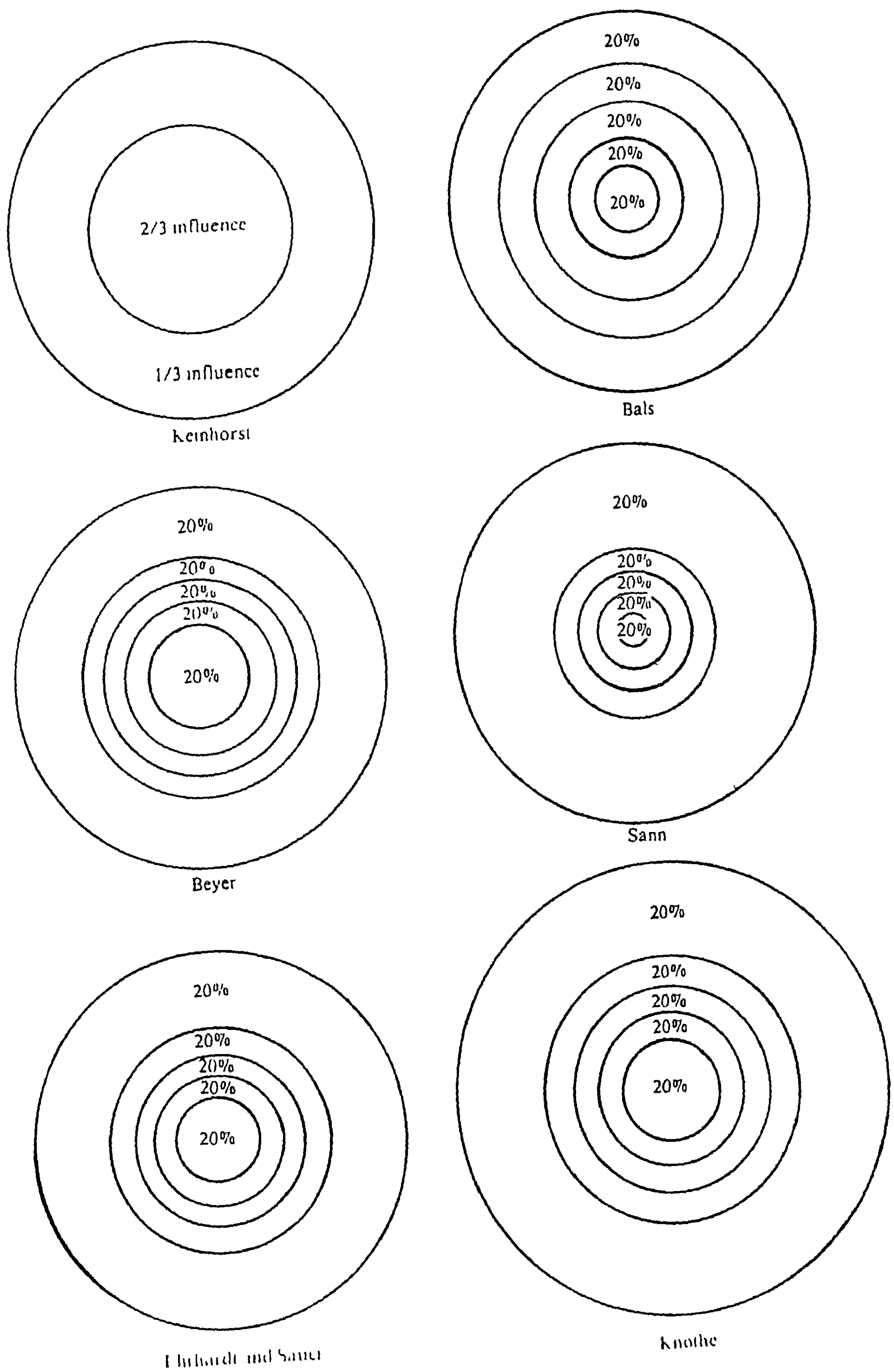

Fig. 4.3 Various influence areas

$$\frac{\partial^2}{\partial t^2}\left(\frac{\partial^2}{\partial x^2} - \lambda^2\right) w = 0 \qquad (5.7)$$

Assuming the solution in the form $w = X(x)\ T(t)$, equation 5.7 will be satisfied if

$$\frac{d^2T}{dt^2} = 0 \qquad (5.8a)$$

and

$$\frac{d^2X}{dx^2} - \lambda^2 X = 0 \qquad (5.8b)$$

Thus,

$$w(x,\ t) = (c_1 + c_2 t)\ (Ae^{\lambda x} + Be^{-\lambda x}) \qquad (5.9)$$

The deflection w is expected to vanish at $x = \infty$, so that $A = 0$, and because for $t = 0$ the deflections due to subsidence are zero it follows that $C_1 = 0$ with $C_2 B = C$,

$$w(x,\ t) = Ct\ e^{-\lambda x} \qquad x \geq 0 \qquad (5.10)$$

The constant c is determined from the condition of vertical equilibrium for any time t.

$$\bar{P} - 2\int_0^\infty q\,dx = 0 \qquad (5.11)$$

with

$$q = \eta\ \frac{\partial w}{\partial t} = \eta\ ce^{-\lambda x} \qquad (5.12)$$

then

$$c = \frac{\lambda}{2}\ \frac{\bar{P}}{\eta} \qquad (5.13)$$

and

$$w(x,\ t) = \frac{\bar{P}\lambda}{2}\ \left(\frac{1}{\eta}\ t\right)e^{-\lambda x} \qquad x \geq 0 \qquad (5.14)$$

measurements. Following two approaches are commonly used in the back analysis techniques:

a) Direct Back Analysis:

The problem is solved by using trial values of the unknown parameters in the algorithm until the agreement between in-situ measurements and corresponding numerical results is reached.

b) Inverse Back Analysis:

Here, the equations governing the problem analysis are inverted, so that some of the quantities unknown but available from the in-situ measurements are used as input data, while the other quantities having known values, appear in the group of unknowns (Bhattacharya et al. 1989).

The direct back analysis technique has been applied here to prediction subsidence by using trial values of material parameters to match the prediction of observed subsidence.

5.4.4 Determination of magnitude of subsidence:

Depending upon the nature of profile obtained in first step the following considerations are made for magnitude prediction of subsidence:

a) Stepped Profile:

In this case overburden is assumed to be rigid and, hence, results obtained in section 5.3.2 is used with a subsidence factor for x lying outside the extracted area.

b) Smooth Profile::

In this case overburden is assumed to be flexible and,

subsidence and subsidence factor has been found to decrease with increase in thickness. Initially (i.e. for smaller overburden thickness), the decreasing rate of subsidence and subsidence factor with increase in overburden thickness is rapid, but in later stage (i.e. for higher overburden thickness) it becomes relatively slow. The variation of logarithmic value of subsidence factor expressed in percentage has been found to be linearly varying with overburden thickness as shown in Figure 6.8).

6.5 Effect of Width on Subsidence and Subsidence Factor

Though, direct relationship has not been illustrated directly through Figures between width and subsidence/subsidence factor. It can be easily inferred from Figures (6.6 - 6.8) that both subsidence and subsidence factor increase with increase in width of excavation. Figure 6.5 also shows that the coal mine with wider width of excavation requires longer time to attain the maximum subsidence value.

6.6 Effect of Width to Overburden Thickness Ratio on Subsidence and Subsidence Factor:

The effect of width to overburden thickness ratio has been studied for the four different cases. In each case width to overburden thickness ratio varies within a wide range with a constant value of overburden thickness of 50 m, 150 m, 200 m and 250 m, respectively. As shown in Figures 6.9, 6.10 and 6.11, subsidence and subsidence factor increase with increasing width to overburden thickness ratio. The

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